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THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

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SOME MEASUREMENTS OF BLENDED SPECTRA

BY RALPH E. DELURY

IN any source of emission or absorption of light, the conditions of the systems, whose vibrations or oscillations account for spectrum lines, are so varied that the lines are never free from the effects of blending. Furthermore, in solar and astrophysical investigations the possibility of the blending of the radiations from several sources arises. Hence it is important that the effects of blending on the measurements of the lines be known. This point was raised by me several years ago,* and the method of blending known spectra in known ways and measuring the resulting lines was suggested as a necessary step in such investigations as the determination of the rate of rotation of eclipsing variables, the presence of a haze or halo of independently moving matter between the observer and the source of light, spectroscopic binaries, etc.; and some few measurements were given of solar rotation spectra blended with sky spectrum. The following measurements of plates taken in 1911 and 1912 and measured shortly afterwards, were made in accordance with those sugges-

* Report of the Chief Astronomer, 1911, pp. 281-4.

tions. Their publication has been delayed in the hope that, with the aid of certain special apparatus, the factors of photographic action, personal interpretation and characters of the spectra blended, could be thoroughly investigated; however, since the results already obtained are quite definite and seem important, they are herewith published.

The method of taking the plates was to expose for a number of seconds, l, on the limbs, using the 23-foot spectrograph with the equipment for observing the rate of the solar rotation by photographing spectra of two opposite limbs simultaneously,* then to move the sun's image so that the centre of the disc fell on the two limb windows in turn, exposing for the same time, c seconds, through each. These times are given in the following Table of Observational Data, for exposures (1) to (10). Exposure (1) is of the limbs alone: exposure (10) consists of a centre strip of spectrum from the centre of the disc, and two outside strips from the receding limb of the sun. In the first column of the table are given the numbers of the plates; in the second the position angle of the limb observations, *i. e.*, the angle between the equatorial diameter of the disc and the diameter joining the limb windows; in the third the ratio of distance of limb window from centre to radius of disc. From exposures *L*915 (10) and *L*917 (10) it is deduced that equal densities of continuous spectrum are obtained by exposures of 50 seconds from a point 0·97 of radius from centre and 21 seconds at centre; and from Abbot's "The Sun," p. 107, it follows that the intensities of these two points for λ5600 are in the ratio 1 : 1·8. Consequently, Density = Intensity × time$^{·97}$ for the Cramer's Iso. Process plates used. Hence, in an exposure of l seconds, limb, followed by an exposure of c seconds, centre, the ratio of density of the *continuous spectrum* from the limb exposure to the total density of the exposure, is,

$$R = c_1^{·97} \div (c_1 + c)^{·97}, \text{ where } 1·8\, c_1^{·97} = l^{·97}$$
$$= l^{·97} \div (l + l_1)^{·97}, \text{ where } l_1^{·97} = 1·8\, c^{·97}.$$

* Report of the Chief Astronomer, 1909 and 1911.

For plate *L*854, the ratio of brightness limb (at 0·91 radius) to centre is 1 : 1·6; hence, in the above formula, 1·6 replaces 1·8. The values of *R* given in the Table of Observational Data and at the heads of columns in the subsequent tables are computed for the various degrees of blending from the above formula.

TABLE OF OBSERVATIONAL DATA

Plate	Position Angle	Limb Distance	(1) l'' c''	(2) l c	(3) l c	(4) l c	(5) l c	(6) l c	(7) l c	(8) l c	(9) l c	(10) l c
L854	0°	0·91	40 39, 1	38, 2	36, 4	32, 8	28, 12					(not blended)
		R =	1·00 0·89	0·83	0·74	0·62	0·54					
L911	75°	0·97	50, 0	45, 3·5	40, 7	35, 10·5	30, 15·5	25, 17·5	23, 23·5	15, 24·5	10, 28	
		R =	1·00 0·89	0·79	0·69	0·58	0·51	0·43	0·33	0·24		
L912	60°	0·97	50, 3·5	50, 0	40, 7	35, 10·5	30, 14	20, 21	25, 17·5	15, 24·5	10, 28	
		R =	0·90 1·00	0·79	0·69	0·60	0·42	0·51	0·33	0·24		
L913	45°	0·97	50, 0	45, 3·5	40, 7	35, 10·5	30, 14	25, 18·5	20, 21	15, 24·5	10, 28	
		R =	1·00 0·89	0·79	0·69	0·60	0·51	0·42	0·33	0·24		
L914	30°	0·97	50, 0	45, 3·5	40, 7	35, 10·5	30, 14	25, 17·5	20, 21	15, 24·5	10, 28	
		R =	1·00 0·89	0·79	0·69	0·60	0·51	0·42	0·33	0·24		
L915	15°	0·97	50, 0	45, 3·5	40, 7·0	35, 10·5	30, 14·0	25, 17·5	20, 21·0	15, 24·5	10, 28	50 25
		R =	1·00 0·89	0·79	0·69	0·60	0·51	0·42	0·33	0·24		
L917	0°	0·97	50, 0	45, 3·5	40, 7·0	35, 10·5	30, 14·0	25, 17·5	20, 21	15, 24·5	10, 28	50 20
		R =	1·00 0·89	0·79	0·69	0·60	0·51	0·42	0·33	0·24		

$R = l0{\cdot}7 \div (l + l_1)0{\cdot}7$, where $l_1 0{\cdot}7 = 1{\cdot}8\, c0{\cdot}7$

$= c_1 0{\cdot}7 \div (c_1 + c)0{\cdot}7$, where $l0{\cdot}7 = 1{\cdot}8\, c0{\cdot}7$

In making the measurements given in the following tables, the Tœpfer measuring machine, (readings to 0·001 mm. and estimations to 0·0001mm.), was used in the same way as for measuring solar rotation displacements, namely, 4 settings on the middle strip (one limb and its blend with centre spectrum), and 2 settings on each outside strip (other limb with its blend with centre). The scale of the plates is 1 Å. u. = 1·42 mm. Half measured displacements and half line-widths were reduced to km./sec. by multiplying by the same factors as used in the determination of solar rotation (varying from 19·34 line 1, to 18·29 line 19). The results of *L*854 are given for each of the 19 spectral lines selected in the 1911 series of solar rotation plates at λ5600, (Table I*a*); and these results are given grouped as to

line-intensity and line-width in Table I*b* ; and again in Table I*c* reduced to the basis : mean rotation displacement = 1·00, where the mean is determined by assigning equal weight to each line-intensity irrespective of the number of lines. Only 11 of the 19 lines, 4 to 14, were measured on plates *L*911 to *L*917, and these results grouped as to intensity and width of lines are given in Tables II*b* to VII*b* ; and in Tables II*c* and VII*c*, reduced to the basis, mean rotation displacement = 1·00, as in I*c*. Under "Line" are given the wave-length, followed by the symbol of the element producing the line from Rowland's Tables ; and under intensity (presumably that of the centre of the sun's disc) as given in Rowland's Tables, followed by measures of the intensities at limb *L*917 (10); in the next column are given the half-widths of the lines at centre and limb from measures of *L*917 (10). Then follow the half-measurements in km./sec. Means are taken for each line and intensity (horizontally) and for each proportion of blending (vertically). In taking the means, the first and tenth columns of these measures are, of course, omitted as they are not measures of blends.

TABLE I*a*.

OBSERVATION—*LS54*, (1 to 16) Spectra of Sun's Limbs at 0°, blended with spectrum of Centre of Disc.

MEASUREMENT—Red right and red left, mean taken; 4 settings middle strip, 2 settings each outside strip each way.

COMPUTATION—Half-Line displacements and half-widths reduced to km./sec.

Line	Intensity		Half-Width		$K=$	0·89	0 83	0 74	0·62	0·54	Means	Residuals
	Centre	Limb	Centre	Limb	1·00						0 72	
5500·095, Mn	1	0	2·2	3·5	1·690	1·603	1·444	1·535	1·120	0·806	1·302	– 0·019
14·503, Ti	2	1-	1·9	2·9	1·560	1·763	1·334	1·603	1·178	0·885	1·353	·032
14·753, Ti	2	1-	2·0	3·3	1·717	1·537	1·327	1·653	0·980	0·878	1·275	– ·046
28·041, s, Mg	8	7	4·6	4·3	1·681	1·704	1·410	1·393	1·331	1·076	1·383	·002
44·157, s, Fe	2	1	2·1	2·6	1·877	1·510	1·428	1·476	1·086	0·868	1·274	– ·047
60·434, Fe	2	1-	1·6	2·5	1·878	1·596	1·512	1·526	1·079	0·847	1·312	– ·009
62·933, Fe	2	1	1·9	2·3	1·613	1·596	1·487	1·523	1·103	0·836	1·321	·000
78·946, Ni	1	0	2·4	2·8	1·816	1·635	1·491	1·479	1·148	0 815	1·314	– ·007
82·198, s, Ca	4	3	2·8	3·2	1·826	1·591	1·444	1·465	1·162	0·908	1·326	·005
90·343, s, Ca	3	3-	2·8	3·0	1·642	1·770	1·516	1·593	1·297	0·907	1·417	·096
98·524, s, Fe	1	0	2·5	3·0	1·670	1·564	1·482	1·476	0·972	0·823	1·263	– ·058
5601·505, s, Ca	3	3-	2·8	2·7	1·753	1·638	1·514	1·420	1·251	0 827	1·330	·000
24·769, s, Fe, V	4	3	4·0	3·4	1·673	1·625	1·440	1·429	1·173	1·012	1·336	·015
38·488, Fe	5	2-	2·5	2·5	1·817	1·584	1·466	1·562	1·085	0·804	1·288	– ·033
58·097, V, –	2	1	2·8	3·1	1·857	1·656	1·405	1·567	1·012	1·028	1·334	·013
82·869, s, Na	5	5	3·9	4·1	1·779	1·614	1·559	1·587	1·213	0·895	1·366	·045
84·710, Si	3	2-	2·6	2·8	1·842	1·604	1·359	1·446	1·031	0·668	1·222	– ·099
86·757, Fe	3	2-	2·8	3·2	1·515	1·742	1·460	1·553	1·010	0·787	1·310	·011
5688·436, s, Na	6	6-	3·6	4·0	1·779	1·642	1·560	1·600	1·231	0·865	1·380	0·059
				Means	1·736	1·630	1·451	1·520	1·133	0·872	1·321	0·000
				Means 1·736	1·00	0·94	0·84	0·88	0·65	0·50	0·76	

Table I*b*

Observation—*L*8554, (1) to (16), See Table I*a*.

Measurement—See Table I*a*.

Computation—Displacements of Table Ia, grouped as to Intensity and Width of Lines.

No. of Lines	Intensity		Half-Width		R =						Means	Residuals
	Centre	Limb	Centre	Limb	1·00	0·89	0·83	0·74	0·62	0·54	0·72	
3	1	0	2·4	3·1	1·725	1·601	1·472	1·497	1·080	0·815	1·293	− 0·047
6	2	1−	2·1	2·8	1·750	1·710	1·416	1·556	1·083	1·090	1·311	− ·029
5	3	2	2·7	2·9	1·714	1·668	1·451	1·515	1·135	0·799	1·313	− ·027
2	4	3	3·9	3·3	1·750	1·608	1·442	1·447	1·168	0·990	1·331	− ·009
1	5	5	3·9	4·1	1·779	1·614	1·559	1·587	1·213	0·859	1·366	+ ·026
1	6	6	3·6	4·0	1·779	1·642	1·660	1·600	1·231	0·865	1·380	+ ·040
1	8	7	4·6	4·3	1·681	1·704	1·410	1·393	1·331	1·076	1·383	+ 0·043
				Means	**1·740**	1·650	1·473	1 514	1·177	0·928	1·340	0 000

Table I*c*

Displacements of Table I*b* divided by 1·740.

No. of Lines	Intensity		Half-Width		R =						Means	Residuals
	Centre	Limb	Centre	Limb	1·00	0·89	0·83	0·74	0·62	0·54	0·72	
3	1	0	2·4	3·1	0·99	0·92	0·85	0·86	0·62	0·47	0·74	− 0·03
6	2	1−	2·1	2·8	1·01	·98	·81	·89	·62	·63	·75 +	− ·02
4	3	2	2·7	2·9	0·99	·96	·84	·87	·65	·46	·76 −	− ·01 +
2	4	3	3·4	3·3	1·01	·93	·83	·83	·67	·57	·77	·00
1	5	5	3·7	4·1	1·02	·93	·90	·91	·70	·49	·79 −	+ ·02 −
1	6	6−	3·6	4·0	1·02	·95	·90	·92	·71	·50	·79 +	+ ·02 +
1	8	7	4·6	4·3	0·97	0·98	0·81	0·80	0·77	0·62	0·80	+ 0·03
				Means	1·00	0·95	0·85	0·87	0·68	0·53	0·77	0·00

TABLE II*b*.

OBSERVATION—Z913, (1) to (9). Spectra of sun's limbs at 75°, blended with spectrum at centre of disc.

MEASUREMENT—Red right; 4 settings middle strip, 2 settings on each outside strip.

COMPUTATION—Half-Displacements and half-widths of lines reduced to km./sec. Displacements grouped as to intensity and width.

No. of Lines	Intensity		Half-Width		$K=$	0·89	0·79	0·69	0·58	0·51	0·43	0·33	0·24		Means 0·56	Residuals
	Centre	Limb	Centre	Limb	1·00											
2	1	0	2·4	2·9	0·307	0·117	0·226	0·253	0·190	0·103	0·160	−0·006	0·043		0·136	0·012
3	2	1−	1·9	2·5	·411	·225	·126	·175	·122	·116	−·016	·047	·010		·101	·047
3	3	3−	2·7	2·8	·395	·307	·167	·187	·121	·065	·068	·160	·067		·147	−·001
2	4	3	3·4	3·3	·391	·324	·205	·297	·093	·139	·093	·061	·031		·107	+·019
1	8	7	4·6	4·3	0·275	0·332	0·367	0·359	0·240	0·067	0·111	0·029	0·002		0·188	+0·040
				Means	**0·374**	0·201	0·236	0·254	0·153	0·098	0·060	0·065	0·065		0·148	0·000

TABLE II*c*.

Displacements of Table II*b*, divided by 0·374.

No. of Lines	Intensity		Half-Width		$K=$	0·89	0·79	0·69	0·58	0·51	0·42	0·33	0·24		Means 0·56	Residuals
	Centre	Limb	Centre	Limb	1·00											
2	1	0	2·4	2·9	1·06	0·31	0·60	0·63	0·51	0·28	0·43	−0·02	0·16		0·36	−0·04
3	2	1−	1·9	2·5	1·10	·60	·33	·47	·32	·31	−·04	·13	·03		·27	−·13
3	3	3−	2·7	2·8	1·06	·82	·45	·50	·32	·17	·18	·51	·18		·39	−·01
2	4	3	3·4	3·3	1·05	·87	·74	·80	·25	·37	·25	·16	·08		·45	+·05
1	8	7	4·6	4·3	0·74	0·89	0·98	0·96	0·64	0·18	0·30	0·08	0·01		0·50	+0·10
				Means	1·00	0·70	0·63	0·68	0·41	0·26	0·24	0·17	0·08		0·40	0·00

Table III*b*.

Observation—Z912, (1) to (9), Spectra of sun's limbs at 60°, blended with spectrum of centre of disc.

Measurement—Red right; 4 settings middle strip, 2 settings on each outside strip.

Computation—Half-Displacements and half-widths of lines reduced to km./sec. Displacements grouped as to intensity and width.

No. of Lines	Intensity Centre	Intensity Limb	Half-Width Centre	Half-Width Limb	$R=$ 1·00	0·89	0·79	0·69	0·60	0·51	0·42	0·33	0·24	Means 0·56	Residuals
2	1	0	2·4	2·9	0·582	0·574	0·491	0·203	0·218	0·110	0·074	0·097	−0·110	0·207	− 0·042
3	2	1 −	1·9	2·5	·611	·608	·525	·258	·176	·064	·116	·037	− ·011	·222	− ·027
3	3	3 −	2·7	2·8	·618	·602	·451	·353	·188	·138	·133	·000	− ·007	·232	− ·017
2	4	3	3·4	3·3	·510	·447	·532	·492	·085	·263	·066	0·08	− ·035	·232	− ·017
1	8	7	4·6	4·3	0·501	0·615	0·503	0·607	0·426	0·292	0·181	0·169	0·000	0·350	+ 0·101
				Means	**0·565**	0·569	0·500	0·383	0·219	0·173	0·000	0·000	−0·033	0·249	0·000

Table III*c*.

Displacements of Table III*b*, divided by 0·565.

No. of Lines	Intensity Centre	Intensity Limb	Half-Width Centre	Half-Width Limb	$R=$ 1·00	0·89	0·79	0·69	0·60	0·51	0·42	0·33	0·24	Means 0·56	Residuals
2	1	0	2·4	2·9	1·03	1·02	0·87	0·36	0·39	0·19	0·13	0·17	− 0·19	0·37	− 0·07
3	2	1 −	1·9	2·5	1·08	1·08	·93	·46	·31	·11	·21	·07	− ·02	·39	− ·05
3	3	3 −	2·7	2·8	1·09	1·07	·80	·62	·33	·24	·23	·00	− ·01	·41	− ·03
2	4	3	3·4	3·3	0·90	·79	·94	·87	·15	·47	·12	·01	− ·06	·41	− ·03
1	8	7	4·6	4·3	0·89	1·09	0·89	1·07	0·75	0·52	0·32	0·30	0·00	0·62	+ 0·18
				Means	1·00	1·01	0·89	0·68	0·39	0·31	0·20	0·11	− 0·09	0·44	0·00

Table IV*b*.

Observation.—*Z*913, (1) to (9), Spectra of sun's limbs at 45°, blended with spectrum from centre of disc.

Measurement.—Red right ; 4 settings middle strip, 2 settings on each outside strip.

Computation.—Half-Displacements and half-widths of lines reduced to km./sec. Displacements grouped as to intensity and width.

No. of Lines	Intensity		Half-Width		K = 1·00	0·89	0·79	0·69	0·60	0·51	0·42	0·33	0·24	Means 0·50	Residuals
	Centre	Limb	Centre	Limb											
2	1	0	2·4	2·9	1·078	0·821	0·622	0·373	0·343	0·254	0·113	−0·025	0·016	0·315	− 0·092
3	2	1 –	1·9	2·5	1·126	·853	·554	·405	·441	·187	·145	·085	·023	·337	− ·070
3	3	3 –	2·7	2·8	1·062	·982	·097	·418	·287	·290	·102	·132	·055	·382	− ·025
2	4	3	3·4	3·3	1·037	·896	·737	·535	·307	·320	·176	·111	·211	·412	− ·005
1	8	7	4·6	4·3	1·139	1·035	0·832	0·509	0·728	0·536	0·478	0·370	0·148	0·588	+ 0·181
				Means	**1·088**	0·917	0·688	0·460	0·421	0·317	0·221	0·130	0·091	0·407	0·000

Table IV*c*.

Displacements of Table IV*b*, divided by 1·088.

No. of Lines	Intensity		Half-Width		K = 1·00	0·89	0·79	0·69	0·60	0·51	0·42	0·33	0·24	Means 0·50	Residuals
	Centre	Limb	Centre	Limb											
2	1	0	2·4	2·9	0·99	0·75	0·57	0·34	0·32	0·23	0·10	−0·02	0·01	0·29	− 0·08
3	2	1 –	1·9	2·5	1·04	·78	·51	·37	·40	·17	·13	·08	·02	·31	− ·06
3	3	3 –	2·7	2·8	0·98	·90	·04	·38	·26	·27	·18	·12	·05	·35	− ·02
2	4	3	3·4	3·3	0·95	·82	·68	·49	·28	·29	·16	·10	·19	·38	− ·01
1	8	7	4·6	4·3	1·04	0·95	0·76	0·52	0·67	0·49	0·44	0·35	0·14	0·54	+ 0·17
				Means	1·00	0·84	0·63	0·42	0·39	0·29	0·20	0·12	0·08	0·37	0·00

Table V*b*.

Observation—1912, (1) to (9), Spectra of sun's limbs at 30°, blended with spectrum of centre of disc.

Measurement—Red right; 4 settings middle strip, 2 settings on each outside strip.

Computation—Half-Displacements and half-widths of lines reduced to km./sec. Displacements grouped as to intensity and width.

No. of Lines	Intensity Centre	Intensity Limb	Half-Width Centre	Half-Width Limb	$R=$ 1·00	0·89	0·79	0·69	0·60	0·51	0·42	0·33	0·24	Means 0·56	Residuals
2	1	0	2·4	2·9	1·273	1·128	0·768	0·471	0·237	0·311	0·104	0·049	- 0·040	0·379	- 0·110
3	2	1 -	1·9	2·5	1·389	1·190	·854	·531	·306	·196	·067	·158	- ·030	·409	- ·080
3	3	3 -	2·7	2·8	1·367	1·197	·992	·572	·400	·267	·079	·192	- ·002	·455	- ·034
2	4	3	3·4	3·3	1·400	1·249	·871	·742	·460	·308	·158	·182	- ·007	·495	+ ·006
1	8	7	4·6	4·3	1·306	1·239	1·058	0·955	0·728	0·586	0·513	0·386	+0·184	0·706	+ 0·217
				Means	**1·347**	1·201	0·909	0·654	0·426	0·334	0·184	0·193	0·009	0·489	0·000

Table V*c*.

Displacements of Table V*b*, divided by 1·347.

No. of Lines	Intensity Centre	Intensity Limb	Half-Width Centre	Half-Width Limb	$R=$ 1·00	0·89	0·79	0·69	0·60	0·51	0·42	0·33	0·24	Means 0·56	Residuals
2	1	0	2·4	2·9	0·95	0·84	0·57	0·35	0·18	0·23	0·08	0·04	- 0·33	0·28	- 0·08
3	2	1 -	1·9	2·5	1·03	·88	·63	·39	·23	·15	·05	·12	- ·02	·30	- ·06
3	3	3 -	2·7	2·8	1·01	·89	·74	·42	·30	·20	·06	·14	- ·05	·34	- ·02
2	4	3	3·4	3·3	1·04	·93	·65	·55	·34	·23	·12	·13	- ·01	·37	+ ·01
1	8	7	4·6	4·3	0·97	0·92	0·78	0·71	0·54	0·44	0·38	0·29	+ 0·14	0·52	+ 0·16
				Means	1·00	0·89	0·67	0·49	0·32	0·25	0·14	0·14	0·36	0·39	0·00

TABLE VI*b*.

OBSERVATION—*Z*915, (1) to (10), Spectra of sun's limbs at 15°, blended with spectrum from centre of disc.

MEASUREMENT—Red right; 4 settings middle strip, 2 settings on each outside strip.

COMPUTATION—Half-Displacements and half widths of lines reduced to km. sec. Displacements grouped as to intensity and width.

No. of Lines	Intensity		Half-Width		K = 1·00	0·89	0·79	0·69	0·60	0·51	0·42	0·33	0·24	1·00 and 0·00	Means 0·50	Residuals
	Centre	Limb	Centre	Limb												
2	1	0	2·4	2·9	1·729	1·582	1·073	0·670	0·409	0·061	0·051	− 0·014	− 0·027	1·026	0·474	− 0·081
3	2	1 −	1·9	2·5	1·866	1·405	1·114	·531	·453	·142	·075	·047	− ·083	·927	·461	− ·094
3	3	3 −	2·7	2·8	1·764	1·640	1·145	·733	·547	·208	·067	− ·033	− ·101	·880	·526	− ·029
(2)	4	3	3·4	3·3	1·742	(1·280)	1·280)	(·841	·557	·406	·067	·010	− ·001	·898	(·559	+ ·004
1	8	7	4·6	4·3	1·773	1·802	1·590	0·970	0·686	0·570	0·202	0·173	− 0·040	0·962	0·755	+ 0·200
				Means	**1·775**	1·542	1·240	0·749	0·630	0·277	0·116	0·037	− 0·050	0·939	0·555	0·010

TABLE VI*c*.

Displacements of Table VI*b*, divided by 1·775.

No. of Lines	Intensity		Half-Width		K = 1·00	0·89	0·79	0·69	0·60	0·51	0·42	0·33	0·24	1·00 and 0·00	Means 0·50	Residuals
	Centre	Limb	Centre	Limb												
2	1	0	2·4	2·9	0·97	0·89	0·60	0·38	0·23	0·03	0·03	− 0·01	− 0·02	0·58	0·27	− 0·04
3	2	1 −	1·9	2·5	1·05	·79	·03	·30	·26	·08	·04	·03	− ·05	·52	·26	− ·05
3	3	3 −	2·7	2·8	0·99	·92	·65	·41	·31	·12	·04	− ·02	− ·06	·50	·30	·01
(2)	4	3	(3·4)	(3·3)	(0·98)	(·72)	(·72)	(·47)	·31	·23	·05	·01	·00	·51	(·32)	+ ·01
1	8	7	4·6	4·3	1·00	1·02	0·90	0·55	0·39	0·32	0·10	0·10	− 0·02	0·54	0·43	+ 0·12
				Means	1·00	0·87	0·70	0·42	0·35	0·16	0·07	0·02	− 0·03	0·53	0·31	0·00

Table VII*b*.

Observation—1917, (1) to (10), Spectra of sun's limbs at 0°, blended with spectrum of centre of disc.

Measurement—Red right; 4 settings middle strip, 2 settings on each outside strip.

Computation—Half-Displacements and half-widths of lines reduced to km. sec. Displacements grouped as to intensity and width.

No. of Lines	Intensity Centre	Intensity Limb	Half-Width Centre	Half-Width Limb	$R=$ 1·00	0·89	0·79	0·69	0·60	0·51	0·42	0·33	0·24	1·00 and 0·00	Means 0·56	Residuals
2	1	0	2·4	2·9	1·776	1·414	1·115	0·493	0·529	0·205	0·436	0·085	0·063	0·897	0·543	− 0·080
3	2	1	1·9	2·5	1·725	1·636	1·071	·000	·505	·074	·269	·000	·114	·949	·534	− ·089
3	3	3	2·7	2·8	1·691	1·413	1·030	·682	·047	·115	·385	·093	·119	·937	·561	·092
2	4	3	3·4	3·3	1·926	1·686	1·148	·792	·603	·300	·459	·071	·144	·939	·658	+ ·035
1	8	7	4·0	4·3	1·583	1·583	1·538	0·943	1·062	0·417	0·620	0·257	0·119	0·786	0·817	+ 0·194
				Means	**1·740**	1·546	1·180	0·702	0·681	0·222	0·434	0·101	0·112	0·901	0·623	0·000

Table VII*c*.

Displacements of Table VII*b*. divided by 1·740.

No. of Lines	Intensity Centre	Intensity Limb	Half-Width Centre	Half-Width Limb	$R=$ 1·00	0·89	0·79	0·69	0·60	0·51	0·42	0·33	0·24	1·00 and 0·00	Means 0·56	Residuals
2	1	0	2·4	2·9	1·02	0·81	0·64	0·28	0·30	0·12	0·25	0·05	0·04	0·52	0·31	− 0·05
3	2	1	1·9	2·5	0·99	·94	·62	·34	·29	·04	·15	·00	·07	·55	·30	− ·09
3	3	3	2·7	2·8	0·97	·81	·59	·39	·37	·06	·22	·05	·07	·54	·32	− ·04
2	4	3	3·4	3·3	1·11	·97	·66	·45	·38	·17	·26	·04	·08	·54	·38	+ ·02
1	8	7	4·0	4·3	0·91	0·91	0·88	0·54	0·61	0·24	0·36	0·15	0·07	0·45	0·47	+ 0·11
				Means	1·00	0·89	0·68	0·40	0·39	0·13	0·25	0·09	0·00	0·52	0·30	0·00

TABLE VIIIb.

Summary of Plates Z_{911} to Z_{917}, means grouped as to intensity and width of lines.

No. of Lines	Intensity		Half-Width		K = 1·00	0·80	0·70	0·60	0·50	0·41	0·32	0·33	0·24	Means 0·50	Residuals
	Centre	Limb	Centre	Limb											
2	1	0	2·4	2·9	1·139	0·930	0·710	0·411	0·321	0·174	0·130	0·033	0·009	0·343	− 0·000
3	2	1	1·9	2·5	1·188	0·980	·707	·417	·334	·130	·100	·062	·004	·344	− ·008
3	3	3	2·7	2·8	1·150	1·024	·747	·401	·305	·181	·154	·096	·012	·384	− ·028
2	4	3	3·4	3·3	1·168	0·980	·811	·617	·301	·289	·175	·074	·061	·421	+ ·009
1	8	7	4·0	4·3	1·181	1·101	0·981	0·734	0·645	0·411	0·366	0·232	0·089	0·507	+ 0·155
				Means	**1·165**	1·000	0·702	0·534	0·405	0·237	0·102	0·089	0·027	0·412	0·000

TABLE VIIIc.

Mean displacements of Table VIIIb, divided by 1·165.

No. of Lines	Intensity		Half-Width		K = 1·00	0·80	0·70	0·60	0·50	0·41	0·32	0·33	0·24	Means 0·50	Residuals
	Centre	Limb	Centre	Limb											
2	1	0	2·4	2·9	0·98	0·81	0·61 +	0·35	0·28	0·15	0·13	0·03	0·01	0·29	− 0·00
3	2	1	1·9	2·5	1·02	·85	·61 −	·36	·29	·11	·09	·05	·00	·29	− 0·00
3	3	3	2·7	2·8	0·99	·88	·64	·42	·31	·16	·13	·08	·01	·33	− ·02
2	4	3	3·4	3·3	1·00	·84	·70	·53	·31	·25	·15	·09	·05	·30	+ ·01
1	8	7	4·0	4·3	1·01	0·95	0·84	0·63	0·55	0·35	0·31	0·20	0·09	0·49	+ 0·14
				Means	1·00	0·86	0·68	0·46	0·35	0·20	0·16	0·08	0·02	0·35	0·00

Table IX.

Plates	Rotation Displacements	Proportionate Rotation Displacements for Intensities 1	2	3	4	8	Mean
*L*911	0·374	0·36	0·27	0·39	0·45	0·50	0·40
*L*912	0·565	0·37	0·39	0·41	0·41	0·62	0·44
*L*913	1·088	0·29	0·31	0·35	0·38	0·54	0·37
*L*914	1·347	0·28	0·30	0·34	0·37	0·52	0·36
*L*915	1·775	0·27	0·26	0·30	(0·32)	0·43	0·32
*L*917	1·740	0·31	0·30	0·32	0·38	0·47	0·36
							0·37

Table X.

l	c	Intensity 1 d	Intensity 1 k	Intensity 2 d	Intensity 2 k	Intensity 3 d	Intensity 3 k	Intensity 4 d	Intensity 4 k	Intensity 8 d	Intensity 8 k	Mean d	Mean k
45	3·5	0·81	1·0	0·85	1·3	0·88	1·1	0·84	1·4	0·95	0·7	0·86	1·2
40	7·0	·61	1·9	·61	1·9	·64	1·7	·70	1·4	·84	0·8	·68	1·5
35	10·5	·35	3·1	·36	3·0	·42	2·4	·53	1·7	·63	1·2	·46	2·1
30	14·0	·28	3·0	·29	2·9	·31	2·6	·31	2·6	·55	1·2	·35	2·2
25	17·5	·15	4·5	·11	6·3	·10	4·2	·25	2·5	·35	1·7	·20	3·3
20	21·0	·13	4·0	·09	5·8	·13	4·0	·15	3·4	·31	1·5	·16	3·2
15	24·5	·03	13·1	·05	7·8	·08	4·8	·06	6·5	·20	1·8	·08	4·8
10	28·0	−0·01		0·00		0·01	27	0·05	5·3	0·06	3·2	0·02	13·5
Interpolated		0·50	**2·4**	0·50	**2·3**	0·50	**2·3**	0·50	**1·8**	0·50	**1·3**	0·50	**2·0**

Table XI.

l	c	Intensity 1 d	Intensity 1 R_1	Intensity 2 d	Intensity 2 R_1	Intensity 3 d	Intensity 3 R_1	Intensity 4 d	Intensity 4 R_1	Intensity 8 d	Intensity 8 R_1	Mean d	Mean R_1
45	3·5	0·81	0·71	0·85	0·72	0·88	0·76	0·84	0·78	0·95	0·83	0·86	0·76
40	7·0	·61	·54	·61	·55	·64	·60	·70	·63	·84	·72	·68	·60
35	10·5	·35	·42	·36	·44	·42	·48	·53	·51	·63	·61	·46	·48
30	14·0	·28	·33	·29	·35	·31	·30	·31	·42	·55	·52	·35	·39
25	17·5	·15	·27	·11	·27	·10	·31	·25	·34	·35	·43	·20	·31
20	21·0	·13	·21	·09	·22	·13	·24	·15	·27	·31	·35	·16	·24
15	24·5	·03	·10	·05	·15	·08	·18	·06	·20	·20	·27	·08	·18
10	28·0	−0·01	0·11	0·00	0·11	0·01	0·13	0·05	0·14	0·06	0·10	0·02	0·13

A glance at Table I*a*. suffices to show that the measured displacements of the blended spectrum lines vary greatly from line to line, being greater as the intensity or width of the line increases. This is shown more positively when the lines are grouped as to intensity and width in Table I*b*. and reduced to the unity basis in Table I*c*., where also a comparison is readily made with the values of R.

Plates *L*911 to *L*917 cover a considerable range of displacements and of proportions of blending. The measurements of these plates — displacements grouped as to intensity and width, Tables II*b*. to VII*b*. — show the same dependence of the measures on intensity. Tables II*c*. to VII*c*. reduced to the basis, rotation displacement = 1·00, are more readily compared with one another. Summarizing the means of the different plates, Table IX., it is seen that there is very little dependence of the proportionate displacements on the initial (rotation) displacement; possibly a slight tendency to smaller proportionate displacements as the initial displacement is increased. This absence of variation of proportionate displacement with initial displacement is, no doubt, due to the fact that the greatest displacement, $2 \times 1{\cdot}78$ km./sec., is only about half of the average width of lines, 2×3 km./sec. Increasing the initial displacements further, (which is, of course, impossible in this case, being restricted by the speed of the sun's rotation), would undoubtedly show greater effect on the measured proportionate displacements. Width of line would then become a more important factor. Since the proportionate values of the measurements do not depend on the initial displacement, the summary of the means of Plates *L*911 to *L*917, for the various proportions of blending of centre and limb spectra, Table VIII*b*., and their proportionate values, Table VIII*c*., may be taken as representative of all measures in the discussion which follows.

The values of Table VIII*c*. are plotted in Figure 1, proportionate displacements, d, plotted vertically and values of R, (*i.e.*, ratio of density of continuous spectrum of limb exposure to density of the continuous spectrum in total exposure), plotted

horizontally. Now an obvious reason to account for the different values of d for various lines is the fact that the ratio of intensity of the centre lines to the intensity of the limb lines varies for different lines. We would expect that if spectra of equal intens-

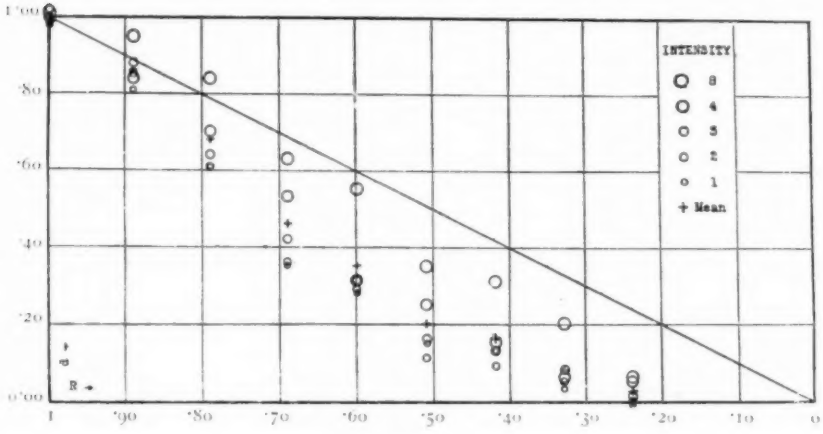


FIGURE 1.

ity—*lines* not *continuous* spectrum—were blended, the value of d would be 0·50; especially as errors of interpretation and photographic effect would be annulled in its measurement. In computing R we have,

$$R = c_1^{0\cdot7} / (c_1 + c)^{0\cdot7}, \text{ where } l^{0\cdot7} = 1\cdot8\, c_1^{0\cdot7},$$

l and c being the times of exposure on limb and then centre, and 1·8 is the ratio of intensity of limb continuous spectrum to centre continuous spectrum. In computing R_1 for any line, however,

$$R_1 = c_1^{0\cdot7} / (c_1 + c)^{0\cdot7}, \text{ where } l^{0\cdot7} = 1\cdot8\, k\, c_1^{0\cdot7},$$

where k = ratio of intensity of centre line to corresponding limb line. Consequently, assuming that $R_1 = d$ for each line, k can be found. These values of k are given in Table X. The values of k are seen to vary considerably for the different degrees of blending, pointing to a cause other than the difference in intens-

ity of the lines in centre and limb. However, it seems safe to assume that this cause is inoperative for values of $d = 0{\cdot}50$ in each case ; so that we may take the values of k interpolated for $d = 0{\cdot}50$ as representing the true ratio of centre line to limb line. Rough visual determinations agree with these values of k. Using these values of k the values of R_1, Table XI., are found. Now plotting d and R_1, Figure 2, we see that the curve of observations, nearly the same for each line, swings symmetrically above

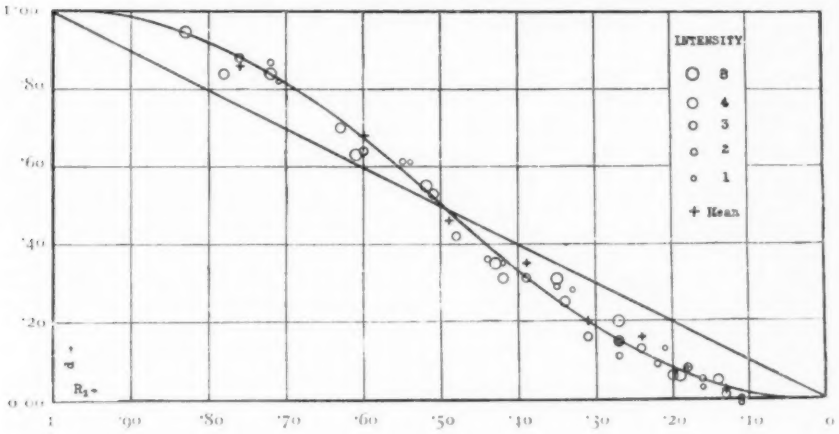


FIGURE 2.

and below the line $d = R_1$. The measurements thus exhibit some tendency common to all lines, possibly due to photographic action but more probably due to interpretation of the blends, *i. e.*, when strong and weak spectra are blended one's measurements tend to give proportionately greater weight to the stronger spectrum. This is in agreement with my measures of the blending of sky spectrum with sun rotation spectra in which the lower proportions of blending showed no appreciable effect of the sky spectrum.

The results found above are applicable to the interpretation of certain peculiarities found in the spectroscopic study of double

stars, the comparison of velocities of stars of different type, and other astrophysical problems; but I shall not discuss these points here. The results are applicable directly to the problem of the determination of the rate of the sun's rotation; in fact the above work was undertaken primarily in the hope that it would offer an explanation of the difference in the rate of the sun's rotation as determined from different spectrum lines (as announced by Adams for his determinations of 1906-1908), and possibly of the greater polar retardation from the spectroscopic observations than from the spots and faculæ. Adams' results have recently been verified by himself and St. John at Mt. Wilson in a manner that leaves little room for doubt as to thier accuracy, though for the period 1911-1913 several other observers found little or no trace of the effect. The assumption of blended spectra during the time of sun-spots and an absence of the effect when the spots are absent offers an explanation of the above observations, but the point will be discussed soon in a separate paper.

The main conclusions of the above work are:

In the measurements of photographs of blended spectra the stronger spectrum asserts itself out of proportion to the relative intensities of the lines measured, the effect being more pronounced the greater the difference in the intensities of the components of the blends.

When spectra, in which the lines have different character and are displaced by amounts ranging up to half the widths of the lines in question, are blended, the measurements of the resulting lines vary from line to line as the relative intensities vary. In the case of blending the sun's limb (lines displaced by rotation) and centre (lines not displaced) spectra, since the relative intensities of lines progresses fairly regularly with intensity (*i. e.*, level in the sun) the measured displacements of the blends progress regularly. In other words, lines of different intensity show different velocities of rotation, the strong lines showing progressively greater values than the weak lines; and since this very effect has been found by some observers in the determination of the sun's rate of rotation it is suggested that at

the time of their observations the limb spectra were blended with spectra in which the lines were less displaced or not displaced at all, such as a strong sky spectrum or spectrum from independently moving matter outside the sun or matter just freshly fallen into the sun and not sharing completely its rotation.

DOMINION OBSERVATORY,
OTTAWA, CANADA,
February, 1916.

THE PSYCHOLOGY OF DIFFERENTIAL MEASUREMENTS

By H. H. Plaskett

Introduction.

A DIFFERENTIAL measurement is the measurement of the distance between a pair of lines. The differential measurements referred to in this paper are measures of the displacements of spectral lines produced by the rotation of the sun. These displacements average about one-tenth of a millimetre, and are converted into radial velocities by multiplication by a velocity constant.

That these differential measurements are subject to certain curious personal effects was first pointed out by J. S. Plaskett and R. E. De Lury.* As an adequate knowledge of the origin and character of these effects is necessary for an exact determination of the solar rotation, the International Solar Union resolved, at its meeting in Bonn, that:

"Investigation should also be made into the personal differences that are found in the measures of the same plate by different observers."

This paper is an attempt at an investigation into the source of these differences. The body of the paper treats of modes of measurement, and indicates the errors introduced by the attitude of the measurer. The method adopted is to gain an insight into the processes of measurement by introspection. An analysis of measures is then made which confirms and adds to the data obtained from introspective evidence. To this is appended a discussion of the errors of measurement of a series of plates taken at Ottawa in the $\lambda 5000$ region. This appendix is supplemental to an investigation on a variation in the rate of rotation of the

Astrophysical Journal Vol. XXXVII., p. 73, 1913.

sun,* and is also of interest as an illustration of the errors of measurement treated in the body of the paper.

Modes of Measurement.

The mode of measurement is defined as the attitude of the measurer during the process of measurement. Two modes of measurement, to be known hereafter as the *attentive mode* and the *automatic mode*, are recognized in this paper, the essential distinction between them being the presence or absence of prepossession. The important part played by prepossession in other mental phenomena is too well known to need further emphasis.† In measurement, on the one hand, by the attentive mode, attention is consciously directed to the results. Prepossession enters, for indubitably a scrutiny of the results is made, either because a clue is sought (the formation of prepossessions), or because a mental comparison is being made with a certain preconceived standard (the operation of prepossession). As long as measurement continues by the attentive mode, prepossessions exist in both a formative and operative condition; the absence of prepossessions implies sooner or later the discontinuance of measurement by the attentive mode. In measurement, on the other hand, by the automatic mode the process is performed in a purely mechanical fashion; no attention is given to the results and hence prepossessions can neither be formed nor be operative. In the remainder of the paper certain important characteristics of either mode of measurement are developed, and a comparison on the basis of facility and accuracy is given.

The Attentive Mode.

An insight into the performance of any skilful act is most readily obtained by a study of the learning process. During the learning process in measurement by the attentive mode, prepossessions are first in the formative stage, later they become crystal-

* *Astrophysical Journal*, Vol. XLIII., March, 1916.

† "Manual of Mental and Physical Tests." G. M. Whipple, Vol. II., p. 222, 1915. "Fact and Fable in Psychology." Joseph Jastrow, p. 296, 1900.

lized, and then practice is required until the results conform to the standard set by prepossession. Only by continuous practice is perfection finally attained. In a time depending upon the amount of previous experience, measurement becomes simplified, the test for conformity with the standard set by prepossession is made with less effort, and the learning process may be said to be completed. A habit of measurement has been formed which, to quote J. R. Angell*, "increases speed and accuracy, while at the same time it diminishes the fatigue of labor."

Habit.—The variable factors in the learning process are previous experience and prepossessions. On account of these variable factors, no two persons will measure the same; each will have his own habit of measurement, affecting all measures equally and giving results that are in error to a greater or less degree. Again, after the lapse of an interval when no measuring has been done ,a measurer will have to practise to attain his former proficiency. These variable factors will now enter the learning process in different degrees, and a new habit of measurement will be formed.

The hypothesis of the formation of a habit of measurement, which gives measures that are in error, is readily confirmed by an examination of measures of the same plates by different measurers. In Table I. will be found the residuals, J. S. P.—H. H. P.,

Table I. J. S. P. – H. H. P.

Latitude	1912	1914
°	km.	km.
0	+ ·021	+ ·003
15	+ ·021	+ ·054
30	+ ·014	+ ·018
45	+ ·011	+ ·016
60	+ ·001	+ ·015
75	+ ·001	+ ·003
80	+ ·019	+ ·004
85	− ·017	− ·003

*Psychology, p. 58, 1906.

for measures of five plates in 1912 and twenty plates in 1914. Both J. S. Plaskett and the writer measured by the attentive mode. Evidence of the existence of a habit for the two measures can be readily seen from these residuals. That these habits have changed in the two years, is shown by the change of residuals. Further evidence of a change in habit is shown by J. S. Plaskett's remeasures of certain equatorial plates.* In an interval of two years his habit had changed by .016 km. From Table I. it would appear that the error produced by this habit varies on the average as the size of the displacement. In equatorial displacements this error is about 0.5μ, and in the higher latitudes it is, of course, considerably less.

Systematic Differences.—Heretofore prepossession has been considered only as entering into the learning process in combination with previous experience to form an individual habit of measurement that affects all measures equally. Prepossession plays, however, another important role in the attentive mode of measurement. It tends to eliminate or accentuate small systematic differences between lines and spectra. It is not necessary to enter into detail. On the one hand, there are prepossessions for consistency and conformity to a certain standard that tend to obliterate these small systematic differences, and, on the other hand, prepossessions for the existence of such differences that tend to accentuate them. Actual numerical illustration is difficult to obtain. The existence of such an effect is shown, however, in the lack of agreement between different institutions as to the existence of systematic differences in velocity for different elements in the chromosphre.

The Automatic Mode.

Measurement by the automatic mode is noteworthy for the mechanical simplicity, or automatism, of the process. So far reaching are the effects of this automatism that it is necessary to understand clearly the conditions that tend to produce it. These

Astrophysical Journal, Vol. XLII., p. 373, 1915.

are, according to E. Boyd Barret*, the sameness of external conditions, simplicity of the process, and a proneness to act quickly. In measurement external conditions are always the same. The simplicity of the process is assured by the lack of control, by the absence of attention and hence of prepossessions. The proneness to act quickly is almost universal. It is this feature that gives a distinguishing mark to the automatic mode of measurement. The tendency is to produce an almost careless attitude on the part of the measurer. "Thus it comes that we will often take any course whatever which happens to be most vividly before our minds, at the moment when the impulse to decisive action becomes extreme."† The conditions that tend to produce automatism are then all present in measurement by the automatic mode. Before discussing the results of this automatism, it is necessary to mention the learning process. Learning is completed when the hand is sufficiently practised to bring the cross hair to that part of the line indicated by the judgment. The only factor that enters the learning process is previous experience.

Primary Habit.—As with the attentive mode, so also with the automatic mode, a habit of measurement is to be expected. This habit will be termed the primary habit. Evidence of its existence is found in the P—D residual in 1911.‡ J. S. Plaskett measured attentively, while R. E. De Lury measured automatically. The mean residual, .03 km, is due to a combination of the errors produced by the two habits. Another example will be found in the measures of the plate *L*867 by the writer. The first five measures were made by the automatic mode, the last seven by the attentive mode. The means are given in Table II. The residuals in the last column show the combination of errors due to the two habits. Note the high accidental error, as shown by the probable errors in the third column, that is so characteristic of measurement by the automatic mode.

* "Motive-Force and Motivation-Tracks," p. 144, 1911.

† "Principles of Psychology." W. James, Vol. II., p. 530, 1890.

‡ *Astrophysical Journal*, Vol. XXXVII., p. 73, 1913.

TABLE II. MEASURES OF *L*867

Latitude	Automatic		Attentive		Au. - At.
	v	p.c.	v	p.c.	
°	km.	km.	km.	km.	km.
0	1·712	± 0·038	1·699	± 0·026	+ 0·013
30	1·387	·040	1·400	·024	- ·013
60	0·551	± 0·043	0·578	± 0·022	- 0·027

An interesting feature of this primary habit is shown in some recent measures. During the summer of 1915 three series of measures of 111 spectra were made automatically by the writer. The plates were taken in the λ5900 region, and contained measurable solar and telluric lines. The solar displacements were due to the equatorial rotation of the sun, while the telluric displacements were caused by instrumental error and were small (from 0-4% of the solar displacements). In Series I., measures were made of five solar and three telluric lines simultaneously on a Repsold machine with an eyepiece micrometer. In Series II., the same lines were measured simultaneously on a Toepfer machine with a 300 mm. screw. In Series III., ten solar lines were measured on a Repsold machine, and five telluric lines on the Toepfer. Applying the same convention of signs to both solar and telluric displacements, and using the means of all the measures, the following Repsold-Toepfer residuals result:

R-T (solar) = +.092 km (I.-II.); + .113 km (III.-II.)
R-T (telluric) = +.072 km (I.-II.); + .045 km (I.-III.).

These residuals are due either to screw errors or to a difference in primary habit with the two machines. An investigation of the screw errors shows that for solar displacements

R-T = —.004 km.

Hence the R-T residual indicates a difference in habit with the two machines. With either mode of measurement a difference in habit is to be expected on account of possible differences in the learning process with the two machines. A difference as large as this, however, is only possible in measurement by the automatic mode, where no attention is given to the results.

Secondary Habit.—Heretofore the learning process has played the leading part in the formation of habits. Depending upon the intensity of certain factors in the learning process, a habit producing errors of greater or less extent is formed. One of the most remarkable features of measurement by the automatic mode is the formation of secondary habits, that can have no connection with learning process. These secondary habits are operative for a short time only, as a rule a day. Their existence is shown by some measures of *L*1677. At one sitting three or four spectra were measured in Series III., and at the same time a measure was made of *L*1677. In this way 58 measures of the

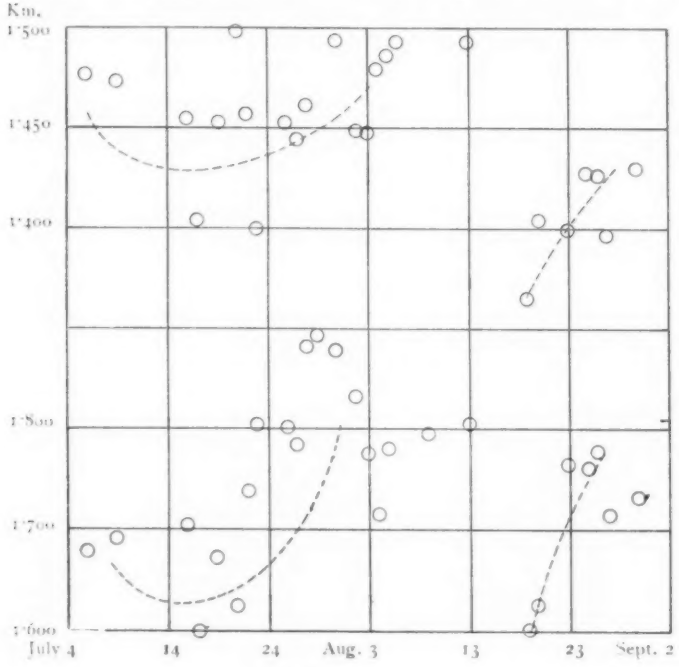


Figure 1.

solar measures of *L*1677

solar lines and 54 of the telluric lines of this plate were made. In the upper half of Figure 1 a graph is drawn, with values of the means of measures of the solar lines as ordinates, and dates of measurement as abscissae. Each circle represents the mean of the measures of *L*1677 for the given day. In order to show the run of values, a curve is dotted through these circles. In the lower half of Figure 1 a like curve, only on one-half the vertical scale, is drawn for the values of the solar lines of the plates of Series III., measured simultaneously with *L*1677. This curve represents an actual inherent variation of the solar lines of these plates due to a cyclic variation of the solar rotation. The close correlation between the two curves is readily seen. This correlation indicates that the measures of *L*1677 have been affected by the measures of Series III. made at the same time. In other words, a secondary habit was formed while measuring the plates of Series III., and misapplied to the measures of *L*1677. Fig. 2 shows the existence of these secondary habits for telluric lines. Further evidence of the existence of these habits is given in the appendix to this paper.

The existence of secondary habits, from a psychological point of view at least, is by no means improbable. In a recent paper, C. H. Judd* has shown that unconscious habits, such as these secondary habits are, show two marked characteristics: (1) a misapplication when transferred to related cases, and (2) an aversion to modification. These secondary habits, while misapplied (see especially the appendix) and difficult to modify during a day, are distinctly ephemeral compared with the unconscious perceptive habits treated by Judd. This ephemerality is due largely to that carelessness that is so characteristic of automatism. A new secondary habit will be formed each day by the measurement of some displacement, persisted in throughout that day, and then carelessly forgotten before the commencement of another day.

Comparison of the Two Modes.

In the preceding sections of this paper the existence and

* "Yale Psychological Studies," N.S. Vol. I., p. 185.

certain important characteristics of the two modes of measurement have been developed. In this section a comparison of the two

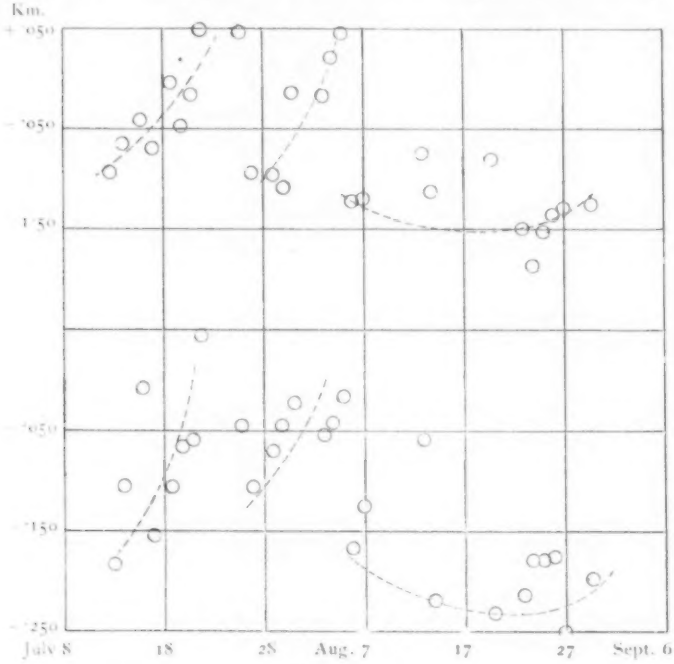


FIGURE 2.

TELLURIC MEASURES OF Δ1677

modes is given on the basis of facility and accuracy of measurement.

FACILITY.—Automatic measures, by virtue of their mechanical simplicity and the non-scrutiny of results, are the easier to make. R. E. De Lury can measure automatically for a whole day without feeling any symptoms of abnormal fatigue. J. S. Plaskett, on the other hand, finds it difficult to measure attentively for periods longer than an hour or two. It is the experience of the writer that more than twice as many lines can be measured auto-

matically as can be measured attentively in the same time. It is evident, then, that where much measuring has to be done, the automatic mode is preferable in that it is the more rapid.

Accuracy.—Accuracy in measurement is essentially freedom from systematic error. One mode of measurement is more accurate than another in proportion to the degree that it is free, or can be freed, from systematic error. The attentive mode of measurement is subject to systematic errors due to (1) a habit of measurement that affects all results equally, and (2) the operation of prepossessions on systematic differences. The error due to habit can be readily removed by measures of a standard plate by different measurers. The error due to prepossession is difficult, if not impossible, to eliminate. Prepossessions are so subtle that it demands the closest introspection to discover them; and even a knowledge of their presence gives no clue as to the amount of error they have produced, or a method by which this error can be eliminated. Error due to prepossession operating on small systematic differences, difficult of elimination as it is, must always vitiate the accuracy of measurement by the attentive mode.

The automatic mode of measurement is subject to systematic errors due to primary and secondary habits. No other systematic error enters the results. The measurer is unbiased, free from prepossession, and indifferent of the results. The errors due to these habits are readily eliminated. If telluric lines or other absorption lines, such as those due to iodine, are impressed on the rotation spectra, then the true velocity, V, of any plate is given by

$$V = S - T,$$

where S is the true mean velocity for the solar lines, and T the true mean velocity for the telluric lines. Now if the measures of the solar lines are subject to an error, a, due to the primary and secondary habits of measurement, and the telluric measures are subject to a like error, b, then the velocity of the plate now becomes v, when—

$$v = (S + a) - (T + b) = V + (a - b);$$

TABLE III.

RESIDUALS IN THE λ5900 MEASURES

Plate	$s_1 - s_2$	$t_1 - t_2$	$v_1 - v_2$	$(s_1 - s_2) - \cdot092$	$(t_1 - t_2) - \cdot072$	$(v_1 - v_2) - 0.20$
	km.	km.	km.	km.	km.	km.
Δ1644	+ ·289	+ ·289	+ ·000	+ ·197	+ ·217	− ·020
1650	+ ·012	+ ·060	− ·048	− ·080	− ·012	− ·068
1654	− ·014	− ·036	+ ·022	− ·106	− ·108	+ ·002
1660	+ ·061	+ ·048	+ ·013	− ·031	− ·024	− ·007
1665	+ ·129	+ ·040	+ ·089	+ ·037	− ·032	+ ·069
1670	+ ·308	+ ·273	+ ·035	+ ·216	+ ·201	+ ·015
1679	+ ·272	+ ·229	+ ·043	+ ·180	+ ·157	+ ·023
1680	+ ·072	+ ·032	+ ·040	− ·020	− ·040	+ ·020
1688	− ·055	·110	+ ·055	− ·147	− ·182	+ ·035
1693	+ ·263	+ ·254	+ ·009	+ ·171	+ ·182	− ·011
1707	− ·105	− ·075	− ·030	− ·197	− ·147	− ·050
1711	− ·013	− ·057	+ ·044	− ·105	− ·129	+ ·024
1723	+ ·248	+ ·237	+ ·011	+ ·156	+ ·165	− ·009
1737	+ ·276	+ ·304	− ·028	+ ·184	+ ·232	·048
1743	+ ·192	+ ·167	+ ·025	+ ·100	+ ·095	+ ·005
1747	+ ·239	+ ·238	+ ·001	+ ·147	+ ·166	− ·019
1754	− ·021	− ·042	+ ·021	− ·113	·114	+ ·001
1756	− ·043	− ·038	− ·005	− ·135	− ·110	− ·025
1757	+ ·075	+ ·079	− ·004	− ·017	+ ·007	− ·024
1762	+ ·112	+ ·090	+ ·022	+ ·020	− ·018	+ ·002
1763	+ ·100	+ ·093	+ ·007	+ ·008	+ ·021	− ·013
1764	+ ·012	+ ·032	·020	·080	− ·040	− ·040
1769	+ ·120	+ ·107	+ ·013	+ ·028	+ ·035	− ·007
1777	+ ·113	+ ·048	+ ·065	+ ·021	− ·024	+ ·045
1778	·072	·112	+ ·040	− ·164	− ·184	+ ·020
1780	+ ·070	+ ·001	+ ·069	− ·022	− ·071	+ ·049
1788	+ ·283	+ ·230	+ ·053	+ ·191	+ ·158	+ ·033
1790	− ·113	− ·126	+ ·013	− ·205	− ·198	·007
1791	·022	·046	+ ·024	·114	·118	− ·004
Δ1792	·033	− ·055	+ ·022	− ·125	·127	+ ·002
Means:	+ ·092	+ ·072	+ ·020	·000	± ·000	± ·000

subject only to errors due to the primary habits, these residuals would have been small, and the run of signs fortuitous. An examination of the table, however, reveals 19 residuals greater than a tenth of a kilometer. These residuals bear the same sign for both solar and telluric residuals, and are evidently produced by secondary habits on the two machines. An examination of the dates of measurement shows, further, that the greater part of these

plates were measured on five days with the Toepfer machine. The interpretation to be given this is that, on the days in question, measurements on the Toepfer machine were made with a secondary habit which produced so large a positive or negative error that it overshadowed the primary habit for both machines, and also, very largely, the secondary habit for the Repsold. When the long previous experience of the writer in measuring on the Repsold machine by the attentive mode is considered, it is not perhaps surprising that this machine is not so fertile of secondary habits. Previous experience must count considerably in such a case.

There is no evidence of a difference in secondary habits for solar and telluric lines. As a typical example, the means of measures of the individual spectra made on one day on the Toepfer machine are given in Table IV. The arithmetic mean of the residuals is

$$v_1 - v_2 = +\,\cdot 003 \text{ km.},$$

an accidentally small quantity. An inspection of these residuals

TABLE IV.

MEASURES ON SEPTEMBER 9

Plate		$(s_1 - s_2) - \cdot 092$	$(t_1 - t_2) - \cdot 072$	$(v_1 - v_2) - \cdot 020$
		km.	km.	km.
Z1711	*a*	− ·157	− ·088	− ·069
	b	− ·147	− ·150	+ ·003
	c	− ·044	− ·154	+ ·110
	d	− ·073	− ·126	+ ·053
1756	*a*	− ·175	− ·125	− ·050
	b	− ·151	− ·085	− ·066
	c	− ·079	− ·121	+ ·042
1791	*a*	− ·212	− ·125	− ·087
	b	− ·101	− ·049	− ·052
	c	− ·097	− ·152	+ ·055
	d	− ·126	− ·117	− ·009
	e	− ·068	− ·191	+ ·123
	f	− ·082	− ·072	− ·010
1792	*a*	− ·089	− ·182	+ ·093
	b	− ·129	− ·108	− ·021
	c	− ·157	− ·092	− ·065

shows two or three greater than a tenth of a kilometer. Out of 111 spectra there are 14 of these large residuals. These appear to be purely accidental in their origin and character. As was pointed out in the earlier paper, these large residuals are most frequently caused by differences in measures of the telluric lines. The telluric lines were not of the best quality for measurement if the plates were taken after 9.00 a.m. On such plates the accidental error of measurement of the telluric lines was high,—hence the high residuals.

This concludes the examination of the errors of the $\lambda 5900$ plates. The errors which were, at first sight, rather puzzling, readily resolve themselves into the two types due to primary and secondary habits. The method of simultaneous measurement of both solar and telluric lines seems to give very satisfactory results. Systematic errors are removed, and, though the fortuitous errors are unfortunately large, the duplication of measurement tends to remove them. In short, the errors of measurement of the $\lambda 5900$ plates, do not seem to vitiate the conclusions obtained in the previous paper.

The writer wishes to acknowledge the kindness of Dr. W. F. King in permitting the publication of this paper.

DOMINION OBSERVATORY,
OTTAWA, CANADA
March, 1916.

A PRISMATIC ARC

Part I.

By A. F. Hunter

THE prismatic arc near the zenith, which was to be seen in Toronto at 4.45 p.m., March 2, 1916, during part of the time of a solar halo, is perhaps worthy of a few remarks. The altitude of the sun at that time was 13° 39′. As usually happens, two parhelia or "mock suns" were visible at the time, and an upper arc, tangential to the primary circle at 22° from the sun, was also present. Some writers call the prismatic arc near the zenith a "circumzenithal arc" (see, for example, *Scientific American*, Sept. 16, 1911), but this term is not well chosen because an arc, in its very nature, does not circumvent or encircle the zenith or anything else, although it may partly do so. And the term is doubly inappropriate if the arc is not part of a circle but part of a parabola, or of a caustic of which the parhelia are the double cusps. No secondary circle at 45° from the sun was to be seen on the above mentioned date; in fact, I have never seen the arc and secondary circle present on the same occasion, and once I measured the arc as 51½° from the sun, which placed it quite beyond a secondary circle, if one had existed; yet some writers speak of it as tangent to the secondary. The arc on March 2 lasted for only about ten minutes after I first observed it, becoming invisible about 4.55 p.m., yet the "mock suns" and tangent to the primary circle remained bright for some time and were still faintly visible at 5.30 p.m. The brief duration of this phenomenon is always one of its chief features, and its occurrence always with about the same altitude of the sun is also worthy of attention, the two features being evidently related to each other. I do not recall having met with any sufficient reference to either of these features.

so I venture to place them on record for readers of the JOURNAL. Other instances of the same phenomenon in the zenith seen at Barrie, Ont., with the times (Eastern standard time) at which I observed them, are as follows:

May 14, 1898, 5.50 p.m. Altitude of sun, 17° 24′.
Sept. 10, 1911, 4.30 p.m. Altitude of sun, 22° 17′.
Feb. 26, 1913, 8.45 a.m. Altitude of sun, 16° 12′.

From the data in hand, therefore, I find a general agreement in the sun's altitude at the times of occurrence, and it is not difficult to understand this if minute prisms of snow or spicula having the same sizes, shapes and positions in the air are the cause of the phenomenon. They would throw the prismatic colors of the rainbow downward almost perpendicularly toward the eye of the observer only when the sun has a particular angle, *i.e.*, only at the critical time when it can be seen. The position of this prismatic arc or "snowbow" at such a high altitude near the zenith will necessarily operate against people commonly observing it, the arc being perhaps too high for casual observers of natural phenomena, and hence it must often go unobserved. Having witnessed on the above mentioned occasion in 1898 the close connection between "mock suns" and the prismatic arc, *viz.*, when one "mock sun" flared out brightly the opposite arm of the arc became bright also, and *vice versa*, the fluctuations appearing to be according to a rule,—I soon formed the habit of looking for the arc when "mock suns" appear, but the search is often without success. It seems to be only when the sun, as a further condition, has approximately the same angle of distance from the zenith that it appears. It may be worth while mentioning also that the arc which I observed in 1913 was exceptional, as neither of the "mock suns" was to be seen, but some other elements of the halo were visible at the time.

A graphic account of the appearance of a prismatic arc during a solar halo may be seen in the TRANSACTIONS of this Society for 1893, page 6 (see below).

TORONTO, March 7 1916.

Part II.

By H. B. Collier

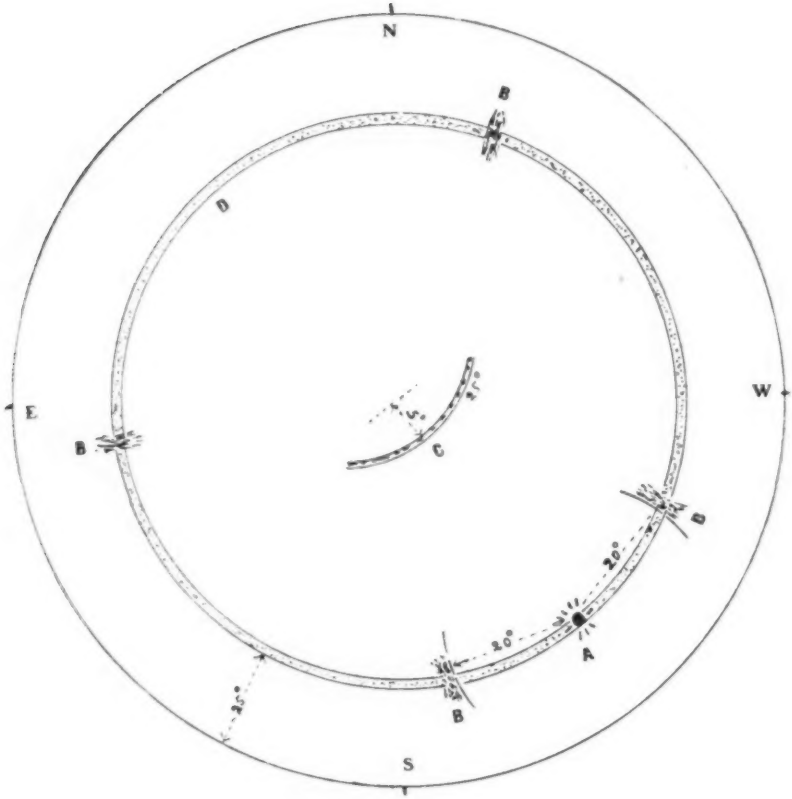
On March 15th, I had the pleasure of witnessing as remarkable a halo as records at hand indicate has taken place, in recent years at least. Never before having looked upon anything of this nature, I am unable to make any comparison. The scores of people who likewise gazed upon the glorious sight, declared that never before had they witnessed anything approaching this. Awed by the phenomenon, many seemed more anxious about its portent than its beauty, and therefore welcomed assurances that no calamity would follow as a result, even though the almanacs had failed to prognosticate the occurrence.

To understand fully the phenomenon, I give the official readings of the thermometer with the weather "Forecast" for the succeeding 24 hours:

March 15th—Noon, 6 above zero F.
2.00 p.m., 7 "
5.30 p.m., 4 "
8.00 p.m., 2 "
10.00 p.m., zero.
Forecast: A few light snowfalls, but partly fair.

At about 4 p.m., when I first noticed the halo, the temperature was 6 degrees above zero, with a bright sun and practically no wind. A careful inspection of the higher air revealed to the eye an atmosphere charged with ice-crystals, yet so diffused as not appreciably to affect the strength of the sun's rays. It was quite impossible for the naked eye to look upon the sun for more than a moment, an evidence of the undiminished brightness. For an hour and a half the phenomenon lasted in all its glory, and at 5.30 gradually faded with the disappearance of the sun in the haze of the western horizon.

I fully appreciate the difficulties before me in endeavoring to visualize by words the glories of such a halo. "Words are things,"



SOLAR HALO AND PRISMATIC ARC

Observed at Viking, Alberta, March 15, 1916.

A, Sun; **B**, **B**, **B**, **B**, Parhelia; **C**, Prismatic or Rainbow Arc; **D**, White Band.

The distances are estimated, no instrumental means of measuring being available.

but I find them very stubborn "things" in an effort to make you see mentally.

To get the picture, place the sun in the south-western sky about 25° above the horizon, with not a cloud in the whole heavens; make the blue-violet depths of unfathomable space, the sole background for this painting. Parallel to the horizon and passing through the sun, a band of white, some two degrees wide, extends around the entire dome. Upon this band are four parhelia or "mock suns," about three degrees in width and extended to some five degrees. Along the inner border of the two parhelia nearest the sun, is a strong band of orange, very narrow, but brilliant, and extending to twice the length of the "mock sun" beside it. At the zenith a brilliant "rainbow" of 25° length, every color being so distinct and clear as to be readily detected by the naked eye. The red end of the spectrum, as it faces the sun, glows as though of liquid fire. There you have before you this strange phenomenon.

As the sun declined, the white band also lowered degree after degree, carrying with it the appurtenances of parhelia as well as the prismatic arc in the high heavens. At 5.15 p.m. this latter feature disappeared, though the white band and parhelia apparently descended with the sun. Strange to relate, the next morning the sun rose with the two parhelia decorated with the orange band accompanying. For an hour or more these were visible, fading as the rays of the sun strengthened.

While viewing this unique solar demonstration, I made drawings and as careful estimates of proportions as my judgment permitted. I trust the sketch which I herewith present, will supplement the description of the phenomenon and assist in a comprehension thereof.

VIKING, ALBERTA.

NOTE.

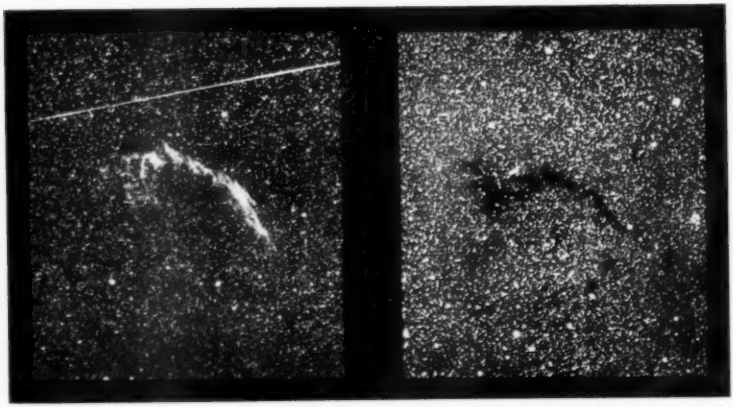
The following is the description of the solar halo seen in

Toronto on February 20, 1893, referred to by Mr. Hunter.—EDITOR.

This apparition seems to have been best seen during the twenty minutes commencing at 9.10 o'lock. Around the sun, at a distance of about 23°, there was a halo, at times well defined. At three points in the halo, north, east and west of the sun, there were bright luminous spots equidistant from each other; no corresponding point south of the sun was noticed. The sun in the centre of a cross, the halo, the brilliant spots, and more especially a short luminous arc north-west of the sun at a distance of about 45°, made up a most interesting object. The arc appeared to occupy a part of the sky otherwise clear, and was remarkable owing to the fact that in the course of a few minutes it disappeared and re-appeared some half-a-dozen times. The convex side of the arc was towards the sun and when at its brightest was tinged with red; the northern side was violet in color.

PLATE II.

NORTH



GASEOUS NEBULA N.G.C. 6995

1909, July 15. Exposure 5h 43m.

DARK OBJECT IN CEPHEUS

Shown on Plate III.

Scale: 1 cm. = 27'

SOME OF THE DARK MARKINGS ON THE SKY AND WHAT THEY SUGGEST*

By E. E. Barnard

OUR knowledge of the universe is confined to the stars and their attendant phenomena and to the nebulæ. It is admitted that there are a great many dark stars, and there is even a claim that there are more dark than bright stars. This is entirely plausible, because we must assume that the stars ultimately die out or cease to give light. That they are everlasting, so far as their light is concerned, is more than improbable. If this is reasonable with respect to the stars, what can be said of the nebulæ? If we can free ourselves from the belief that the function of a nebula is to become a star, or stars, we can imagine some similar condition to that of the stars to prevail among these great bodies, that is, that they may become dark in the course of time. Should this be true we shall have space peopled with bright and dark nebulæ. Indeed, we shall have all grades between a bright nebula and one entirely devoid of light.

Photographs of the sky often show us large dark markings comparable in size with the nebulæ, scattered here and there over the heavens. They are found especially in the region of the Milky Way. The first impression these objects give is that they are openings in the rich regions of stars through which we look out into the blackness of space beyond. The more familiar we become with them, however, the less this explanation appeals to us, and we soon begin to suspect that most of them are really dark or feebly luminous bodies shown in relief against a brighter background. Some of them are undoubtedly real vacancies, or places where the stars are actually thinned out, but these

*Reprinted with the author's approval from the *Astrophysical Journal*.

particular ones at once proclaim their nature and leave one in little doubt as to their explanation.

At present we are interested only in those dark markings that give the impression of being real objects and not simply vacancies. What their nature is we do not know, and the spectroscope cannot help us because the objects are devoid of light, or nearly so. But there is strong evidence that they are of the nature of the nebulæ — that is, that they are dark nebulæ.

Some of the dark stars make their presence known by their perturbing effect on the motions of bright stars, and by the eclipsing of their light. Their existence would otherwise be unknown, for their angular dimensions are too small for them to be seen in relief against any luminous background. Non-luminous nebulæ, though their presence may never be known by any disturbance in neighboring bodies, would, if more or less opaque, be large enough to be seen if projected against a brighter background.

I think the general belief among astronomers is that a nebula remains luminous, and finally develops into a star or system of stars — that is, its ultimate destiny is a stellar condition. This opposes any supposition that a nebula may become dark by the loss of its light. For the presence of a dark nebula, however, it is not necessary that it should have lost its light. It may never have been luminous. It is possible that the original condition of a nebula is dark. It may be that some nebulæ never become luminous, or it may still be possible that there are great non-luminous, opaque bodies in space that are not necessarily related to the nebulæ, though this is, perhaps, far-fetched. From the fact that some of the nebulæ appear to be partly dark and partly transparent, we might infer that they may, in the course of time, become either wholly bright or wholly dark.

In the case of Hind's variable nebula in Taurus, we have undeniable proof that a nebula may lose its light. Some fifty or sixty years ago this nebula lost all or most of its light, and from

a conspicuous object in a small telescope, it ceased to be visible even in the most powerful instruments. Though it is again feebly visible in very powerful telescopes, it is mainly by photography that we can see it at all. What has occurred to this may happen to any other nebula, but the changes may take a much longer period of time.

I have shown that in certain cases a nebula may be opaque, or partly so. This is strikingly evident in the case of the great nebula about ν Scorpii and the one about ρ Ophiuchi* (Plate IV.). In the case of the first of these nebulæ it was shown that parts of it seemed to transmit the light of the stars behind it, and other parts — especially the darker or more obscure portions — seemed to cut out the light of the stars entirely. This possible opacity of a nebula leads us to a probable explanation of some of the smaller starless regions. That they are due to the interposition of masses of dark nebulosity seems more than probable, especially as long-exposure photographs frequently show feeble traces of nebulosity in these starless spots. A striking illustration of this is shown in the dark spot in Taurus (1855·0, $\alpha = 4^h\ 10,^m\ \delta = +27^\circ\ 55'$) where what appears to be a dark hole in the sky is exactly filled with excessively feeble nebulosity with dark details†. There are other equally striking examples of this connection of feeble nebulosity with vacancies. Perhaps a more remarkable example of this condition is that of the great nebula of ρ Ophiuchi and its immediate surroundings. All that is needed to make these dark bodies visible is a luminous region behind them. This is supplied in one way by the rich stellar regions of the Milky Way. An excellent example of how such a thing may be possible is shown by a phenomenon that presented itself to me one beautiful transparent moonless night in the summer of 1913, while I was photographing the southern Milky Way with the Bruce telescope. I was struck with the presence of a group of tiny cumulus clouds scattered over the rich star-clouds of Sagittarius. They were remarkable

**Astrophysical Journal*, Vol. XXXI, p. 8, 1910.

†*Astrophysical Journal*, Vol. XV., p. 218, 1907.

for their smallness and definite outlines — some not being larger than the moon. Against the bright background they appeared as conspicuous and black as drops of ink. They were in every way like the black spots shown on photographs of the Milky Way, some of which I was at that moment photographing. The phenomenon was impressive and full of suggestion. One could not resist the impression that many of the black spots in the Milky Way are due to a cause similar to that of the small black clouds mentioned above — that is, to more or less opaque masses between us and the Milky Way. I have never before seen this peculiarity so strongly marked from clouds at night, because the clouds have always been too large to produce the effect.

Enough has been said, perhaps, to show that, whatever their condition may have been or may become, there are dark opaque objects scattered here and there over the heavens, which resemble, in all but light, the regular nebulæ of the sky. Perhaps if we show a close resemblance in form and size of one of these to one of the well-known nebulæ, it may aid us in connecting the two kinds of objects. For this purpose I have prepared Plate II. from my photographs, which shows two different objects in different parts of the sky, one representing the bright nebulæ and the other the "dark" nebulæ. The photographs are on exactly the same scale and show that the two objects are of almost exactly the same angular size. The first is the nebula *N. G. C.* 6995 in Cygnus (1860·0, $\alpha = 20^h\ 51^m$, $\delta = +30°\ 41'$), the other a dark marking recently found by me in Cepheus, in the position: 1860·0, $\alpha = 20^h\ 48^m$, $\delta = +59°\cdot6$. There is a striking resemblance in the forms of the two objects; but one is a luminous nebula and the other a dark — what? One can readily see that if the nebula were to lose its light, it would, if dense enough, still be shown against the sky and would strongly resemble the dark object. For this and many other reasons I am constrained to believe that the dark object is really a non-luminous nebula seen against a luminous background. There is no visible evidence of the ordinary nebulosity in the immediate

region of this dark object; that is, the background is not the ordinary diffused nebulosity so frequently shown on photographs, nor is the stellar stratum dense enough to serve as a luminous background. There is every evidence in the original photograph of a continuous, uniform luminosity over this entire region that is real and not due to the ordinary fogging of the plate by atmospheric luminosity. The idea has, therefore, suggested itself to me, and the suggestion has been strengthened by the appearance of other regions, that there is possibly a feeble luminosity in space, sufficienty strong to impress itself on the sensitive plate by prolonged exposures. I am, of course, familiar with the fact that our atmosphere is more or less luminous and that it fogs the plate with prolonged exposures, but palpably this could never serve as a background for the distant nebulæ.

That the "dark" nebulæ of Plate II. is between us and the stars in this region is clearly proved by the fact that it blots out the few stars that must be behind it. From an inspection of the original negatives it is clear that its visibility is not due to that fact, however, for the stars are too few at that point to serve as a luminous background.

That this luminous condition of the sky is widely extended in this region is shown by the presence of another similar, but much smaller, dark spot on the same plate, one degree south of α Cephei, which has a small star in it. This small object is close to and south of the 8·9 magnitude star *B. D.* + 61°2903. It is in the position 1855·0, $\alpha = 21^h\ 11^m{\cdot}2$, $\delta = +\ 61°{\cdot}8$, and is well shown on Plate III

This last plate shows near its centre a large fragmentary ring of nebulosity, part of which seems to be connected with a nebulous star, *B. D.* + 57°2309 ($6^M{\cdot}5$). It lies in the position, roughly, $\alpha = 21^h\ 10^m$, $\delta = +\ 58\frac{1}{2}°$.

On the eastern edge of the plate is part of a remarkable nebula which is ramified with singular "dark lanes," which somewhat resemble the dark lanes in Taurus.* The nebulous star (+ 57°2309) and nebulosities mentioned above were first

**Astrophysical Journal*, Vol. XXV., p. 218, 1907.

shown on my plates with the Willard lens taken at the Lick Observatory.*

Two photographs were made with the 6-inch and 10-inch lenses of the Bruce telescope on September 30 and October 1, 1910, with exposures of $5^h\ 5^m$ and $6^h\ 2^m$ respectively. Plates II. and III. were made from the second of these negatives. I had hopes of making an entire night's exposure on this region, but the conditions have not been favorable. Such a long exposure was begun on October 9, 1915, with the dark object central on the plate, but after nearly six hours the sky suddenly clouded. The resulting negative verifies the other two, and shows that the marking is apparently on the sky itself, that is, it is not due to the presence of any ordinary nebulous background. Though this marking is purely a silhouette, and has no detail on its surface, there is much detail in the outline of its eastern end, which is more or less convoluted and has sharply defined projections from it like the horns of an insect. The body of it is much broken up.

If I have proved that there are dark objects in the heavens that are shown on photographs through being projected on a luminous ground I have opened the way to prove something else. This very fact of there being a luminous background may prove of the greatest value to us in our solution of the problems of space, because one form of this background suggests a feeble luminosity through interstellar regions and perhaps beyond.

If we assume that dark and opaque bodies exist in space, we could expect their presence to be shown by several means, all of which must be capable of producing a luminous background for the object. The kind of background will also give us some idea of the relative distances of these dark bodies. Such a body, if between us and the Milky Way, would appear black and conspicuous. We have many cases where such objects apparently exist in the Milky Way. One of the finest examples is that of the small black spot in a bright star cloud in Sagittarius (1855·0, $\alpha = 18^h\ 7^m$, $\delta = -18^\circ\ 17'$), which seems to be

*See *Publications of the Lick Observatory* Vol. XI., Plate 82.

an opaque body in relief against the mass of bright stars. If one of these bodies were projected against a nebulous ground it would also be visible. We have examples of this, one being the dark spot in the nebulous strip running south from ζ Orionis,* which is probably a darker mass of the nebula itself, seen in relief against the more luminous portion of the nebula. Another beautiful example of this kind is shown in photographs of the very elongated nebula 24 Comæ† (*N.G.C.* 4565), which seems to be an object similar to the great nebula of Andromeda, with its edge toward us, where the darker outer periphery of the nebula is seen cutting across the brighter central region as a black irregular streak.

These examples are exceedingly interesting and important, because in the case of those objects seen against the Milky Way, it shows that these dark nebulæ in many cases are nearer than the small stars that form the main body of the Milky Way. This in itself is not surprising to me, for we have many examples of bright nebulæ that must be nearer than the more distant stars, such as the great nebula of ρ Ophiuchi, parts of which are also opaque nebulosity, and the nebula about σ Scorpii. Both of these are intimately connected with bright stars and must be relatively near to us. But there are others of these dark bodies that do not have a bright stellar background to show them, for they are seen in regions poor in stars, nor does their visibility depend upon the ordinary nebulous background, for there are no evidences of such nebulosity in the regions in which they appear. Without the stellar background or the presence of ordinary nebulosity, these dark objects should not be visible. That they are distinctly visible against the sky under these circumstances would suggest that, as their visibility would absolutely depend upon a more or less luminous background, that the sky beyond, for some reason, is itself luminous. If this uniform luminosity covered a very large region of the sky without any definite form or structure, there might arise a suspicion

* *Astrophysical Journal*, Vol. XXXVIII., 496, 1913.

† See W. S. Franks, *Monthly Notices*, Vol. LXV., 160, 1904.

that distants pace itself is more or less feebly luminous. There are a number of these dark spots whose presence is due to projection against a luminous background other than that produced by stars or nebulosity. They look like dark markings on the sky itself.

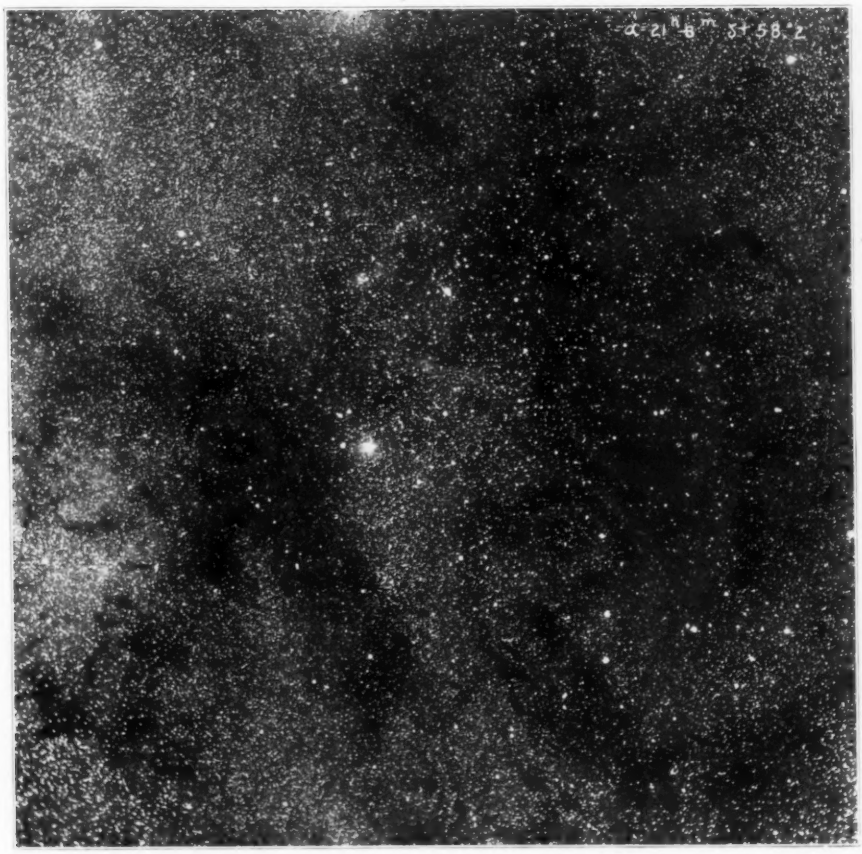
What is the cause of this luminous background where there is no ordinary nebulosity and where the stars are too few to produce it? There seems to be one possible explanation. Let us suppose space to be filled with the feeblest luminosity, so feeble, indeed, that at the distance of the fixed stars it is not sensible. Then, as space is supposed to be of very great extent, this luminosity would increase in apparent density until it would finally become dense enough to affect the sensitive plate. This then would serve as a background to show in relief any large non-luminous object that might exist in space.

It is not necessary to attempt here any explanation as to the cause of this supposed luminosity of space. Indeed, there is no direct claim that it actually exists. It is only suggested as a possible cause of certain phenomena that seem best interpreted by its presence — and from the further fact that the photographic plate seems to show its existence over large regions of the sky.

In respect to the illustrations: on the original negative the dark object is but feebly contrasted with the sky. To show it more clearly it was necessary, in order to gain contrast, to copy it repeatedly. This has produced the coarse grain on Plate II. and gives the impression of a dense stellar background which only partly exists — the west portion of the object being projected on a much richer region of stars. The original plate is slightly fogged to the right of the dark nebula, which produces the luminous appearance close to the edge of the plate. The small plate is intended mainly to show the form of the object. The large one gives a truer representation of this region of the sky, with the exception of the slight fogging at the right side of the plate. The bright line on the photograph of *N.G.C.* 6995 is a large meteor trail.

PLATE III.

NORTH

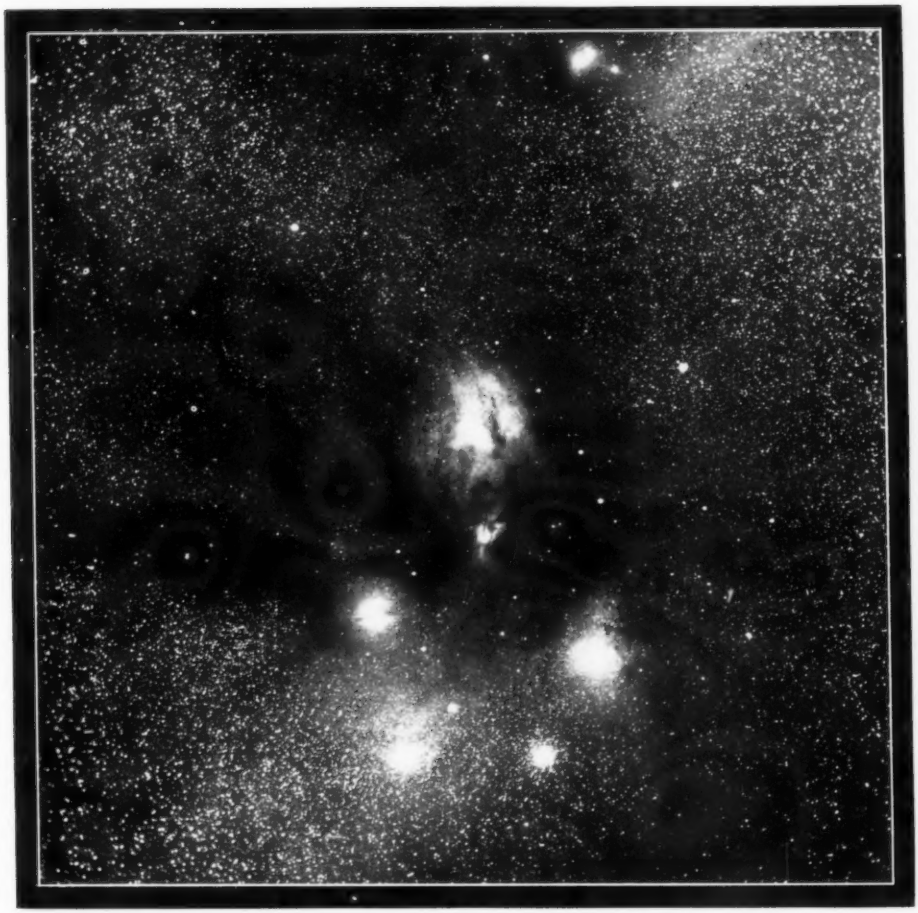


REGION OF MILKY WAY SOUTH OF ALPHA CEPHEI, SHOWING TWO DARK OBJECTS AT POINTS INDICATED

10-inch Bruce Telescope. 1910 Oct. 1. Exposure 6h 2m
Center at $\alpha = 21^h\ 8^m$, $\delta = +58°{\cdot}2$ (1855·0). Scale: 1 cm = 34′·8

PLATE IV.

NORTH



GREAT NEBULOUS REGION OF ρ OPHIUCHI

10-inch lens. 1905, April 5, $19^h\ 45^m$ to $24^h\ 15^m$ G.M.T.

Scale: $1^\circ = 16{\cdot}7$ mm.

The plate covers $7^\circ{\cdot}7 \times 7^m{\cdot}7$.

An important fact that may come from our knowledge of the existence of dark nebulæ is that their masses must be much greater than would be assumed for the ordinary nebulæ, because they are perfectly opaque and must be relatively dense, and hence comparatively massive. If this is so, then, we must take into account these great masses in a study of the motions of the stars as a whole.

YERKES OBSERVATORY,
WILLIAMS BAY, WIS.
October 26, 1915.

MEETINGS OF THE SOCIETY

At Toronto

February 22nd, 1916.—A regular meeting of the Society was held in the Rooms, 198 College St., Mr. A. F. Hunter in the chair.

Mr. Percy Taylor, Miss A. L. Armstrong and Mr. J. M. Faircloth, all of Toronto, were elected members of the Society.

The paper for the evening was to have been given by the Rev. Dr. Marsh, of Holstein, dealing with the planet Saturn, but as he had been taken seriously ill on the day before the meeting, he was unable to be present.

The Secretary, with the aid of a number of Professor Chant's lantern slides, undertook the paper as announced and proceeded to review our knowledge of the planet Saturn up to the present time. Special reference was made to the recent work of Professor Lowell at the Flagstaff Observatory which indicated that there is more or less fluctuation in the position of the various rings with respect to each other and to the surface of the planet; the "Cassini" division, for example being at times within or beyond its normal position, and varying in width. This behavior of the ring is attributed by Professor Lowell to the tidal action of the satellites and the varying strata of the planet itself.

March 7, 14 and 21.—A course of three lectures designed as a grounding in Astronomy, as previously arranged, was delivered

by Professor Chant, in the Physics Building of the University of Toronto.

The lectures were illustrated by lantern slides and various models, and were well attended by the general public as well as the members. The subject of "Things in the Sky and How to See Them," was dealt with as follows:—

March 7—I. The sphere formed by the sky; the apparent motions of the sun, moon and stars every day; of the moon every month; of the sun every year; how the sky is mapped; explanation of Right Ascension and Declination; how to identify the stars by the use of the star-maps; why the stars change with the seasons.

March 14—II. The moon; its daily motion, rising and setting; its motion each month; meaning of phases, and how produced; why the full moon is high in winter and low in summer; the 'old moon in the new moon's arms'; when the moon can 'hold water'; harvest moon and hunter's moon; its influence on the weather; its appearance in the telescope; occultations of stars; eclipses of sun and moon.

March 21.—III. The planets; how to distinguish them from the fixed stars; why they appear to go forward, stand still and go backward at times; why Venus is sometimes an evening, sometimes a morning, star; when to look for Mercury; phases shown by Mercury and Venus; appearance of the planets in the telescope.

April 1.—A regular meeting of the Society was held in the Society's Rooms at 198 College St., Mr. A. F. Miller in the chair.

The following were elected members of the Society:—

H. Lindsley, University of Toronto.

Geo. Humphrey, 42 Major St., Toronto.

Edward T. Wilkie, 56 Marmaduke St., Toronto.

Rama Varma Raja, Trivandrum, Travancore, South India.

Photographs of the Sun's Surface, taken by Professor Hale, of Mt. Wilson Observatory, were exhibited by Mr. J. R. Collins.

Dr. A. D. Watson was called upon to give his address on "Companions of the Sun." In a very pleasing manner he guided the audience over the Solar System, pointing out all the most interesting features in a very profitable way, after which by request, he read his poem on Copernicus.

W. E. W. Jackson, *Rec.-Sec.*

NOTES FROM THE METEOROLOGICAL SERVICE

Summary Report of the Weather in Canada

March, 1916

Temperature.— The temperature was above the average in the southern portion of the Interior of British Columbia, also for the most part well above over Alberta and the western half of Saskatchewan, elsewhere in the Dominion it was everywhere below the average, and in nearly all localities to a marked extent. The chief positive departures were 7° at Calgary and Medicine Hat, and the pronounced negative departures were 9° at White River, 8° at Ottawa, 7° at Southampton, Quebec, St. John, and Charlottetown, and 6° at Port Stanley, Montreal and Yarmouth.

Precipitation and Depth of Snow on the Ground.— The precipitation was above the average over British Columbia, Saskatchewan, Manitoba and in Ontario, as far as the Georgian Bay District and the western portion of Lake Ontario, average or a little below in Alberta and well below the average in Eastern Ontario, Quebec and the Maritime Provinces. The chief positive departures were 8·40 inches at Vancouver; 2·70 inches at Victoria; and 1·30 inches at Minnedosa; and the most noticeable negative departures were 2·10 inches at Quebec and Father Point; 2·20 inches at Halifax; and 1·80 inches at St. John. The precipitation over the greater portion of the Dominion was largely snow, which had pretty well melted in numerous local-

ities by the 31st. At the close of the month, Cariboo in Northern British Columbia, reported 18 inches of snow on the ground, and Glacier, in the Selkirks, over 6 feet. Northern Saskatchewan had from 4 to 10 inches; Manitoba about 4 inches, except locally, where there was much more; Northern Ontario from 14 to 36 inches; the Ottawa Valley from 7 to 18 inches; Quebec from 8 to 24 inches; and Charlottetown in Prince Edward Island 10 inches: over the remaining portions of Canada the snow had either completely disappeared or a few traces only were left.

Temperature for March, 1916

Station	March		Station	March	
	Highest	Lowest		Highest	Lowest
Yukon			Huntsville	62	-26
Dawson	46	-40	Kenora	48	-29
British Columbia			Kinmount	62	-31
Atlin	41	-22	Kingston	54	-12
Agassiz	56	27	London	61	- 6
Barkerville	54	0	Lucknow	48	-14
Kamloops	64	15	Markdale	52	-15
New Westminster	55	25	North Gower	50	-20
Prince Rupert	51	20	Oshawa	54	-11
Vancouver	53	29	Ottawa	58	-16
Victoria	58	31	Paris	63	- 8
Western Provinces			Parry Sound	56	-18
Battleford	48	-30	Peterboro'	60	-18
Calgary	64	-12	Port Arthur	48	-19
Edmonton	57	-20	Port Burwell		
Medicine Hat	68	-18	Port Dover	56	-15
Minnedosa	42	-36	Port Stanley	51	- 9
Moose Jaw	50	-29	Queensborough	58	-27
Oakbank	45	-34	Ronville	58	-24
Portage la Prairie			Southampton	49	- 9
Prince Albert	50	-32	Sundridge		
Qu'Appelle	45	-30	Stonecliffe	60	-28
Regina	38	-33	Stony Creek	59	- 4
Saskatoon	43	-28	Toronto	57	- 2
Souris	42	-35	Uxbridge	59	-15
Swift Current	56	-33	Wallaceburg	55	- 1
Winnipeg	41	-36	Welland	59	-13
Ontario			White River	56	-49
Agincourt	58	- 8	*Quebec*		
Aurora	54	-15	Brome	63	-17
Bancroft	62	-25	Father Point	46	- 8
Barrie	56	-11	Montreal	54	- 6
Beatrice	56	-22	Quebec	48	- 9
Berlin	59	-10	Sherbrooke	59	- 7
Bloomfield	54	-11	*Maritime Provinces*		
Brantford			Charlottetown	44	- 8
Chapleau	57	-40	Chatham	58	-12
Chatham	62	1	Dalhousie	46	- 7
Clinton	51	-16	Fredericton	60	-17
Collingwood	45	-10	Halifax	54	- 2
Cottam	56	3	Moncton	57	- 8
Georgetown	58	- 7	St. John	53	- 2
Goderich			Sussex	59	-15
Gravenhurst	56	-25	Syndey	50	- 6
Grimsby			Yarmouth	52	5
Guelph	57	- 6			
Haliburton	62	-30			

Earthquake Records by the Milne Seismograph
Toronto

R. F. Stupart, Director.

P.T. = Preliminary Tremors. L.W. = Large Waves. A.C. = Air Currents.
Time is Greenwich Civil Mean Time, 0 or 24 h = midnight.

No.	Date 1916	P. T. Comm.	L.W. Comm.	Max.	End	Max. Amp.	Durat.	Remarks
		h m	h m	h m	h m	mm.	h m	
1555	Feb. 1	S 8 2·9	8 9·9 S 16·2	8 44·2	10 33·2	1·7	2 30·3	Repeat [10h 28m·7 to 10h 33m.2.
1506	" 6		11 13·2	11 37·4	11 46·4	0·2	0 33·2	
1557	" 6	22 1·0 ? S 22 11·2)	22 23·5 ? 22 25·1)	22 34·8	0 24·5?	4·8	2 23·5	9·024 km.
1558	" 8	15 52·6 S 16 3·3	16 15·6	16 18·6	16 49·8?	0·6	0 57·2	
1559	" 10		12 3·8	12 10·5	12 31·0	0·5	0 27·2	
1560	" 14		10 42·8?	11 35·7	11 54·2	0·3	1 11·4	
1561	" 15	11 45·8? S 11 50·3	11 53·7	12 01·0	13 15·2?	1·6	1 29·4	
1562	" 20	Attending inst. S 18 5·2	18 13·3	18 26·3	20 0·2	2·8		
1563	" 22		19 25·6		19 27·8	0·05	0 2·2	
1564	" 22	No Pts.	21 1·5	21 6·1	21 18·5	0·4	0 17·0	
1565	" 27	20 29·2	20 37·1	20 42·2	23 55·2	9·7	3 26·0	
1566	" 28		20 19·8		20 27·1	0·1	0 7·3	

Period 18 seconds. 1 mm. = 0″·50.

VICTORIA, B. C.

F. N. DENISON, SUPERINTENDENT.

No.	Date 1916	P.T. Comm.	L.W. Comm.	Max.	End	Max. Amp.	Durat.	Remarks
		h m	h m	h m	h m	mm.	h m	
1560	Feb. 1	7 54·2 S 7 57·2	7 58·7	7 59·2	8 07·6	0·3	0 13·4	1,730 km.
1561	" 1	S 8 16·0	8 25·0	8 28·4	9 38·8	0·9	1 22·8	
1562	" 3	5 05·7	5 06·2	5 06·7	5 10·7	0·4	0 5·0	270 km.
1563	" 6		11 09·3	11 10·6	11 17·6	0 2	0 8·3	
1564	" 6	21 58·2 S22 5·8	22 9·2	22 19·5	0 4·7	2·5	2 6·5	
1565	" 8		15 54·7			0·1		
1566	" 10		11 44·8	11 52·7	12 03·6	0·4	0 18·8	
1567	" 15	11 40·1 S11 43·3	11 45·8	11 46·8	12 41·8	6·0	1 1·7	2,230 km.
1568	" 20	17 50·6 S17 53·9	17 58·1	18 15·0	19 49·1	1·5	1 58·5	1,910 km.
1569	" 22	19 21·6	19 22·1	19 22·4	19 24·3	0·3	0 2·7	Local tremor felt 4h. (120th meridian time). Not recorded.
1570	" 27	20 32·4 S20 37·0	20 43·0	20 55·6	22 43·0	8·0	2 10 6	4,960 km.

Period of boom 18 seconds. Pillar deviation 1 mm. = 0″·54

J. V.

MAGNETIC OBSERVATIONS

FEBRUARY, 1916

During the month of February the Magnetic Forces, as indicated by the photographic records obtained at Agincourt, were unusually quiescent. The curves were classified as quiet from the 1st to the 4th, on the 8th, 9th, 11th, 16th, 21st, 25th and 29th and on other days as being lightly disturbed. No specially noteworthy perturbations were recorded.

February, 1916		D. West	H	Z	I
		° ′			° ′
	Mean of Month	6 32·2	0·16010	0·58574	74 42·8
	Maximum	6 44·7	0·16058	0·58593	
	Date of Maximum	18	21	23	
	Minimum	6 19·5	0·15962	0·58526	
	Date of Minimum	12 and 13	8	22	
	Monthly Range	0 25·2	0·00096	0·00067	
Mean Daily Amplitude	From hourly readings	0 8·1	0·00034	0·00006	
	From means of extremes	0 12·3	0·00048	0·00015	

H. and Z. are given in C.G.S. units and beginning with this issue are reduced to the International Magnetic Standard. The corrections for the Agincourt instruments were determined from a series of observation made in Washington in November and December, 1915, and a series made in Agincourt in April, 1916. The results of these comparisons are as follows:

I.M.S. = Agincourt + 0·00033 parts of H.

The correction on Z is proportional to that on H.

I.M.S. = Agincourt − 0′·93. (Declination.)

I.M.S. = Agincourt − 0′·15. (Inclination.)

For Declination, East Declinations are to be considered positive and correction is to be applied algebraically.

W. E. W. J.

ASTRONOMICAL NOTES

A Variation in the Solar Rotation.—Conclusions.—1. A refinement of instrumental conditions led to results practically free from instrumental error.

2. Measures of each plate were made in duplicate. On account of the difficulty of measurement of the small telluric displacements there were a few large accidental errors.

3. The results were inconclusive as regards variation within a day, if the range be less than one-tenth of a kilometre. There was no evidence of a variation with a range greater than this.

4. There was good evidence of a cyclic variation extending over a month with a range of 0·15 km. Too short an interval was covered by the observations to make possible any statement as to periodicity.

5. The mean of all the measures showed that the rotation in 1915 was 0·04 km. lower than it was in 1913.

6. These results were in general confirmed by a discussion of previous spectroscopic determinations of the solar rotation.—H. H. Plaskett, in *The Astrophysical Journal* for March, 1916.

Comets and Meteors of 1915.—In *B. A. A. Journal*, Vol. XXV. 6, the Rev. M. Davidson points out that only two comets since 1892 appear to have approached near enough to the earth's orbit to make meteor showers from their debris possible, *viz.*, 1900 III. (Giacobini) and 1906 V. (Kopff), which was an apparition of Finlay's Comet 1886 VII. In the former case the meteor radiant would be at 267° + 50° about October 10, which is in fairly good agreement with a radiant observed by Denning

about that time of the year. The latter, however, (*B. A. A. Journal*, Vol. XXV., 7), considers the connection uncertain, as meteors are to be seen shooting from the same position at various other periods of the year. There is no meteoric shower at present known which can be connected with Comet 1906 V. (Kopff).—*Monthly Notices R. A. S.*, No. 4.

HARVARD COLLEGE OBSERVATORY, *Bulletin 606.*—A cablegram received at this Observatory from Copenhagen announces the discovery of a planet by Wolf, at Konigstuhl, in the following position :—

April 27·4124 G.M.T.
R.A. 12h 40m 16s·0,
Dec. + 2° 24′ 0″.

The object, which had a cometary appearance, had a daily motion of − 32ˢ in R.A. and + 5′ in Dec. and was visible in a large telescope.

Bulletin 607.—A telegram received at this Observatory from Professor E. B. Frost gives the following position of an asteroid, probably the object found by Wolf, as derived from a photograph :—

G.M.T.	R.A.	Dec.	Observer	Place
	h m s	° ′ ″		
April 24·6361	12 47 32·7	+ 1 59 60	Barnard	Yerkes Observatory

The object was visible in a large telescope The position is probably correct within five seconds of arc.

The position indicated above would place the object in the Constellation Virgo.—EDWARD C. PICKERING, Director.

MEETING OF ROYAL SOCIETY OF CANADA.—The 1916 Meeting of Royal Society of Canada will be held at Ottawa from May 15th to 17th inclusive. The General Meeting and Meetings of Sections will be held in the Chateau Laurier. The Presidential Address and Popular Lectures will be delivered in the Chateau Concert Hall.

PROPER MOTION OF THE ORION NEBULA.—M. J. Comas Solà has obtained direct evidence that the annual proper motion

of the great nebula is about 0·025″ by stereoscopic comparison of photographs. The near by small nebula, A.G.C. 1917, shows equal motion, but in the opposite direction, and it is considered to be in orbital relation with the first.—*Nature*, No. 2425.

MARTIAN SEAS.— If the high albedo of Jupiter and Venus is significant as to the composition of their visible surfaces, the low albedo of the darker parts of Mars is equally significant. Using reflecting telescopes of 8½ and 10¾ inches aperture, I have often remarked that the darkest spots on Mars, the Syrtis Major, Mare Sirenum, Sinus Sabæus, and some others, appeared nearly as dark as the sky behind the planet. Lately, using a very fine Calver reflector of 18 inch aperture, I have been still more struck by the darkness of these areas. Their albedo must be not far from zero. Now there is nothing we know of capable of so eating up light as to reflect practically none of it, except *a deep layer of something transparent*. The inference is irresistible that these areas consist of *deep water*. In other words they are what they appear to be — seas.— WM. F. A. ELLISON, in *The Journal B. A. A.*, February, 1916.

FAINT STARS WITH LARGE PROPER-MOTION. — Two discoveries of faint stars possessing very large proper-motions have been announced recently. Mr. Innes discovered, by means of his blink-microscope, a small star near α Centauri with a visual magnitude of about 10^{m} and a photographic magnitude of 12^{m}— and, hence, a red star—with a proper-motion of about 5″ per annum. Only five larger proper-motions are known, all belonging to much brighter stars. The position for 1900 is 14^{h} 22^{m} 55^{s}, − 62° 1′·6. Dr. Max Wolf has discovered a star of 11^{m} (photographic) which has an annual proper-motion of 2″·6. The position for 1875 is given as 1^{h} 56^{m} 3^{s}, + 5° 7′·1. The proper-motion appears to be largely parallactic, and the star will probably be found to have a large parallax.—A. C. D. CROMMELIN, in *The Observatory*, No. 499.

J. R. C.

With deep regret we have to announce the death of Dr. W. F. King, Chief Astronomer for Canada, which took place at Ottawa, on Sunday, April 23, 1916. A fuller notice will appear in the next issue of the JOURNAL.

NOTES AND QUERIES

Communications are Invited, Especially from Amateurs. The Editor will try to Secure Answers to Queries.

QUERIES

1. I saw it stated in the press lately that we should not again see such a conjunction as the recent one of Venus and Jupiter for 100 years: is that so?

2. What would be the limiting size of a sun-spot visible to the naked eye? Recently two very fine spots were visible through smoked glass and in describing them to several to whom I pointed them out I stated that the earth could be dropped into them. I hope I was telling the truth.—T. H. WINGHAM, Hamilton.

ANSWERS

1. There will be a conjunction of Venus and Jupiter on May 5th, 1917, in which the two planets apparently come much closer together than in 1916 but they will be too close to the sun to be observed. However, there is another conjunction on July 26th, 1918, when the apparent distance between them is not much greater than at the time of the recent conjunction. This conjunction will be visible in the morning sky, the planets being about two hours west of the sun.

2. A sun-spot would have to be at least one minute of arc in diameter to be seen by even the most experienced observer,

but such a spot would have a diameter more than three times the diameter of the earth. It is therefore quite safe to say that the earth could be dropped into any spot visible to the naked eye. Spots have been observed with a diameter of approximately one hundred thousand miles — more than twelve times that of the earth.

OTTAWA. R. M. MOTHERWELL.

THE AURORAS OF ICELAND: THEIR HEIGHTS

In the *Scientific American* for April 15 appears an interesting letter bearing on this subject written by Frimann B. Arngrimsson, of Akureyri, Iceland, (N. Lat. 65° 40′). He reports that some magnificent auroras have recently been seen in Iceland, notably during the former half of October and the latter half of November. The finest of all were on the 13th of November, the description of which I quote :—

> Between 6 and 7 o'clock in the evening of that day, there appeared suddenly a stream, or wand, of light above the horizon and to the northwest of this town. In a twinkling of an eye this stream of light extended itself across the heaven forming an arc of continuous light even to the western horizon. The latter is formed by a range of mountains 1,500 metres high and 15 kilometres distant, while along the eastern horizon runs a heath about 1,000 metres in height and 6 kilometres distant. The arc of auroras crossed the sky just beneath the Great Bear constellation, and remained there growing in brightness for a few moments, resembling an immense band or fringe of light, made up of dazzling lances or spears of ethereal flame moving from east to west and west to east like a vast line of infantry. Then, this arc was paralleled by another which crossed the Great Bear constellation; a third crossed by the Pole Star; a fourth crossed the zenith; a fifth a little to the south; and a sixth and a seventh arc crossed the Pleiades. The seven arcs formed a bridge of continually moving light completely across the heavens.
>
> This continued for some 10 to 15 minutes, during which time the auroras assumed at times various colors reflected by the moonlight. Then the most northerly arc faded away as did also the most southerly arcs, but the second, the third and the fourth arcs remained a few moments longer, when they broke up and rolled themselves into a vast spiral of dazzling light which outshone the stars and hid from view the cirrus clouds immediately above it.

I question the correctness of the statement that the colors

are due to reflected moonlight. Several other displays are also described; they were usually seen between 6 and 8 p.m., and occasionally showed all the colors of the rainbow.

The writer of the letter states that the heights of the auroras seen on the 21st of November were between 3,000 and 9,000 metres, and the most northerly arc seen then was only some 12 kilometres north of his station. These distances he deduces from the fact that at times the auroras were bright enough to hide some cirrus clouds immediately above them and were, therefore, at a lower elevation than these, but they were decidedly above the cumulus clouds which covered part of the sky.

In a recent number of this JOURNAL was given an account of Stormer's work on determining the height of the aurora by a method which can hardly be questioned, and his heights for auroras, apparently similar to those observed in Iceland, were usually in the neighborhood of 100 kilometres. Now there is good evidence, in my opinion, that sometimes the aurora is quite close to the earth, but I cannot avoid the suspicion that determinations of height by reference to clouds are of doubtful validity.

THE TWILIGHT BOW

This is a phenomenon which is not very often observed, or at least is seldom reported, and during the coming summer months I hope some of the readers of the JOURNAL may be able to see it. The matter was recalled to my attention on reading recently H. Y. Hind's "Narrative of the Canadian Red River Exploring Expedition of 1857 and of the Assiniboine and Saskatchewan Exploring Expedition of 1858" (Vol. II., p. 380), where the following passage occurs:—

One of the most beautiful celestial phenomena visible after sunset and before sunrise from the north-west prairies is the Twilight Bow. The extraordinary clearness of the nights during summer in this region offers a very favorable opportunity for witnessing the delicate coloring which is communicated to the

lower atmosphere by the reflected light from the upper illuminated portions. As the appearance of the Twilight Bow is dependent upon the serenity of the atmosphere to a great degree, its occurrence is not frequently observed or recorded in this country.

The Twilight Bow, and the causes which produce it, are thus described by M. Bravais :—"Immediately after the setting of the sun, the curve which forms the separation between the atmospheric zone directly illuminated by the sun, and that which is only illuminated secondarily, or by reflection, receives the name of *Crepuscular curve* or *Twilight Bow*. Some time after sunset, this bow, in traversing the heavens from east to west, passes the zenith ; this epoch forms the end of civil twilight, and is the moment when planets and stars of the first magnitude begin to be visible. The eastern half of the heavens being then removed beyond solar illumination, night commences to all persons in apartments whose windows open to the east. Still later the Twilight Bow itself disappears in the western horizon ; it is then the end of the astronomic twilight ; it is closed night. We may estimate that civil twilight ends when the sun has declined 6° below the horizon, and that a decline of 16° is necessary to terminate the astronomic twilight."

I often observed the Twilight Bow to be tinged with a delicate rose color, passing into straw color, and then into faint emerald green. The line of demarcation between the bow and the illuminated portion of the atmosphere was often very well defined, quite as clearly as in a secondary rainbow. It appeared most brilliant at an altitude of 60° or 70° above the horizon. It descended slowly towards the boundless level, preserving apparently with considerable exactness the form of a parabola.

THE LATEST NEWS FROM MARS

The fourth Observation Circular issued by the Lowell Observatory, dated March 30, 1916, is as follows :—

A curious set of features, secondary to the main canal network, have become

apparent on Mars. Within some of the polygons made by the intersections of the larger canals a tiny dot has been descried at this observatory, joined to a corner and to the sides of the polygon by lines so slender they usually appear as a string of minute beads. The effect is of a centrally woven web, spun within the borders of the polygon, of a more minute order of tenuity than the polygon itself. Elysium was the first example of this phenomenon with the Fons Immortalis and five connecting spokes. A second has just been detected in eastern Arcadia, the region bounded by the Acheron, Lapadon, Clarius and Psillis; the Fons Senectutis and four spokes reproducing the same singular arrangement. These details are so minute and so curiously disposed as to suggest a new order of Martian markings

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BOOKS ADDED TO THE LIBRARY

Books added to the Library since the last list published, (October, 1915) . –

"Altitudes in Canada," by James White, 1915.

"Dictionary of Altitudes," by James White, F.R.S.C., F.R.G.S., 1916.

"Forest Protection in Canada in 1913-14," Commission of Conservation.

"Atlas of Canada," Chief Geographer, 1915.

"Dernières Pensées," by Henri Poincaré, 1913.

"La Théorie du Rayonnement," Rapports et Discussions publ. par MM. P. Langevin et M. de Broglie, 1911.

"An Introduction to the Study of Variable Stars," by Caroline E. Furness, Ph.D., 1915.

"Atmospheric Circulation and Radiation," by Frank H. Bigelow, 1915.

"How to Identify the Stars," by Willis I. Milham, Ph D., 1914.

"The Great Pyramid," by Richard A. Proctor, 1898.

"Ten Years' Work of a Mountain Observatory," by G. E. Hale, 1915.

"A Voyage in Space," by H. H. Turner, 1915.

"A Few Chapters in Astronomy," by Claudius Kennedy, 1898.

C. A. C.